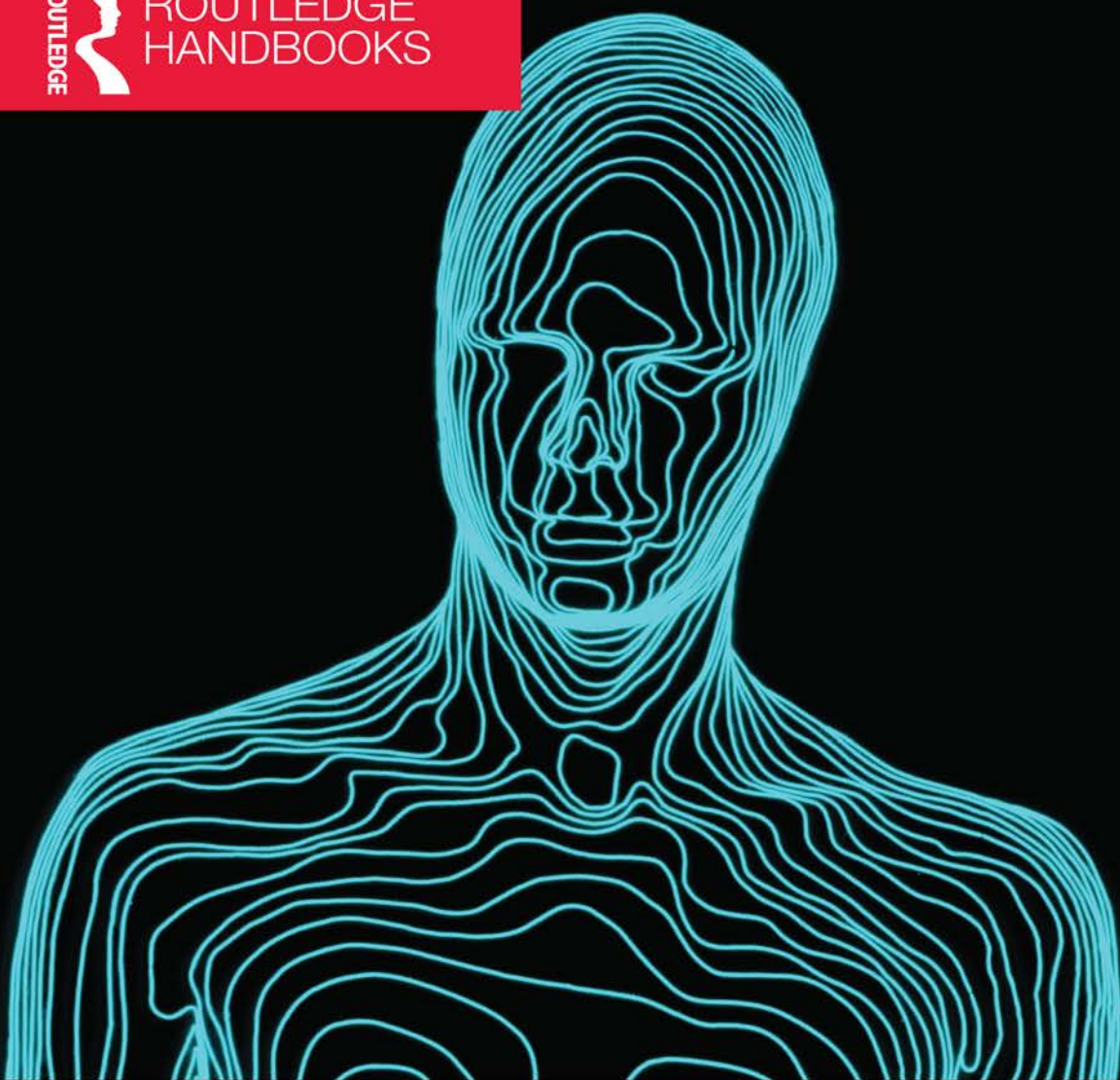




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Edited by Lawrence Shapiro

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INTRODUCTION

Lawrence Shapiro

The thirty-five chapters within this handbook, all appearing in print for the first time, aim to situate, motivate, illuminate, illustrate, and critically evaluate embodied cognition in all its facets. The authors of the individual chapters already enjoy the status of leaders in their respective fields or have been chosen because they are well on their way. Whether seeking to understand the historical roots of embodied cognition, gain perspective on the variety of distinct approaches that practitioners of embodied cognition employ, witness the array of cognitive functions to which ideas of embodiment have been applied, or consider the nature of cognition and the extent to which a focus on embodiment marks a shift from the methods and mores of conventional cognitive science, this book answers the call.

The first two chapters set the scene for current research in embodied cognition, tracing its ancestry back to quite distinct lineages. Shaun Gallagher describes a cluster of ideas arising from within the phenomenological tradition that have influenced contemporary thinking on the body's role in cognition, from Husserl's notion of the "I can" that characterizes the objects of perception in terms of what our bodies can do with them, to the Merleau-Pontean appreciation of the motor processes involved in perception. Phenomenology, Gallagher argues, remains crucial as well in neuroscientific investigations of experience insofar as it provides the tools for describing those aspects of experience that correlate with neural activity.

Coming from an entirely different tradition, Claire Michaels and Zsolt Palatinus offer a biblically inspired recounting of ecological psychology, in which the axioms of the Gibsonian approach are crystallized in ten commandments. Their case study of the famous outfielder problem illustrates a number of principles that, while not universally adopted, have attained prominence in embodied cognition, such as the role of action in creating opportunities for perception, and an antagonism toward representationalist and computationalist accounts of information processing. Their claim that the ten commandments of ecological psychology must be accepted as a complete package might best be evaluated in the context of the many chapters in this book that seem not to obey this prescript. Similarly, the chapters to follow provide ample material with which to assess the importance of phenomenological thinking in a contemporary science of cognition.

Following this section on the historical antecedents of embodied cognition is a collection of chapters dedicated to presenting a variety of perspectives on what it means to describe cognition as embodied, or on what embodiment brings to the study of cognition. These chapters develop

themes that recur in the chapters of the next, applied, section, thus situating them in a theoretical context.

Ken Aizawa examines arguments for the claim that embodiment, in some cases, suffices to extend cognitive processes beyond their traditionally conceived boundaries within the skull. Focusing on two such arguments – one involving the idea of cognitive equivalence and the other on special forms of connection between the brain and the world – Aizawa carefully considers the burdens such arguments face as well as the distinctions, such as those between derived and non-derived content, and between causal influence and constituency, that matter to their assessment.

Michael Richardson and Anthony Chemero’s presentation of dynamical systems approaches to cognition and neuroscience delivers an accessible guide to a related group of concepts, such as self-organization, soft assembly, and non-linearity, that promises to revolutionize the study of cognition. Dynamical approaches are rewriting the rule book for investigating cognitive capacities such as problem solving, and posing challenges to entrenched conceptions of mind such as the view that cognition is significantly modular.

Laila Craighero, a neuroscientist, shows how the embodiment of cognition arises from activity in seven functionally distinct brain areas. Included in her discussion are the celebrated mirror neurons, the study of which continues to have a profound impact on theories of social cognition. Craighero discusses evidence that implicates the motor system in encoding goal-directed actions, just as the auditory system might encode sound, and suggests various reasons that such a system might have evolved, including the opportunity it creates for reusing knowledge of the consequences of previous actions and facilitating the acquisition of new motor skills.

Michael Dawson grapples with the distinctions between embodied, embedded, and situated cognition, drawing contrasts to standard cognitive science. He illustrates these distinct versions of embodied cognition through an examination of echolocation in bats. Conceiving of the bat as embedded, or situated, in its environment is necessary for understanding its use of informational feedback in capturing prey, and appeal to features of the bat’s body, such as the shape of its ears, is necessary to understand how it solves the underdetermination problem of perception that vexes traditional cognitive theories.

The idea of embeddedness develops even further in Di Paolo and Thompson’s chapter on enactive theories of cognition. Di Paolo and Thompson explain the centrality of the concept of autonomy in enactivist psychology. Autonomy refers to the capacity of organisms to maintain their distinctness from their environments while at the same time constantly exchanging matter and energy with their environments *in order* to retain their distinctness. They develop the idea of a *precarious operationally closed system* and show how such a system, in the course of adapting to its environment, creates norms that dictate a kind of relevance for action. Cognition, for the enactivist, involves regulating the body so that it adapts to the world for the sake of its own preservation.

With historical groundwork set, and perspectives on embodiment clarified, the handbook turns next to specific research projects that build on this history and adopt these perspectives. The chapters in this, the largest section of the book, display the range of embodied research *across* the cognitive domain, and *within* particular cognitive domains. The topics covered are perception, language, reasoning, social and moral cognition, emotion, awareness, memory and attention, and group cognition. The three or four chapters dedicated to each topic bring to life the creativity, novelty, and insight that vindicates much of the current excitement over embodied cognition.

With a focus on perception, Marc Leman and Pieter-Jan Maes show how music perception depends on modalities of behavior such as movement, emotion, and interactions with the environment. Among their interesting findings are that motor activity associated with positive

emotions leads to higher preference ratings for music, and facilitates recognition of melodies in major keys, while negative emotions heighten sensitivity to melodies in minor keys. Erik Myin and Jan Degenaar pursue an enactive approach to vision, defending a theory that seeks to replace cognitivist conceptions of vision, which depend on a framework of rules and representations, with one that emphasizes an organism's history of interactions with the environment. Through this history, an organism attunes the sensorimotor contingencies that make visual perception possible. Finally, Cedar Reiner and Jeanine Stefanucci discuss space representation, using it as an example to illustrate the tight connections between perception and action. Perception, they claim, functions to plan for action, but also constitutes a kind of action in virtue of sharing a representational code.

The four chapters devoted to language start with Daniel Casasanto's provocative defense of the body-specificity thesis, according to which an organism's body determines how it conceptualizes the world. In a number of studies involving subjects that differ in handedness (left- or right-dominant), Casasanto reveals how handedness influences perception and judgment, and how simply wearing a ski glove on one's dominant hand can induce changes in perception and judgment. Michael Kaschak, John Jones, Julie Carranza, and Melissa Fox present their work on language comprehension, arguing that comprehension depends on the construction of internal sensorimotor simulations. Building on this idea, they offer a solution to the notorious symbol grounding problem – a problem that has motivated many researchers to abandon traditional cognitivism in favor of embodied theories. Claudia Scorolli investigates more precisely which features of sensorimotor simulations participate in language comprehension and explores the effect of grammar on simulations. Of particular interest is her account of how bodily simulations might contribute to the comprehension of abstract nouns and verbs. Finally, Chen Yu looks to embodiment to resolve issues concerning the indeterminacy of reference. Relying on machine learning techniques, Yu focuses on interactions between the child's body, the body of the language teacher (usually the parent), and the environment in order to explain how the task of reference fixing becomes tractable.

The next topic, reasoning, spans a broad variety of distinct phenomena. Martha Alibali, Rebecca Boncoddio, and Autumn Hostetter extend their research on gesture to show how gesture contributes to reasoning, arguing that we gesture as a result of mentally simulating bodily actions. Gestures are, in effect, the body's response to the brain's inability to suppress all the activation it generates when simulating action. Their data show that subjects gesture more frequently when describing information they've learned through physical actions than e.g. through vision; and gesture facilitates even abstract reasoning with numbers. James Dixon, Damian Kelty-Stephen, and Jason Anastas illustrate how dynamical systems theory might be used to explain performance on particular reasoning tasks, such as card sorting and gear problems. Essential to their approach is a conception of organisms as dissipative structures that self-organize. On this view, the explanatory tools of thermodynamics can be made to serve in explanations of cognitive phenomena. Mitchell Nathan describes the relationship between mathematical reasoning and embodiment, drawing on research to show how mathematical ideas become grounded in perceptual experiences and body-based actions. Finger movements in particular seem integral to capacities for mental arithmetic, at least in some stages of development. Last in this section, Tarja Susi examines human performance in computer gameplay. The game constituting her case study reveals the subtle influences that bodily motions and postures play in problem solving, and also suggests ways in which cognition might extend into physical and virtual environments.

Social and moral cognition has been an especially active research area within embodied cognition. Shannon Spaulding explains the subject matter of social cognition and then

distinguishes embodied theories from the two prevailing theories: *theory theory* and the competing *simulation theory*. Spaulding presents embodied accounts of social cognition as a deflationary alternative, in the sense that they eschew mentalistic and representational resources, instead explaining social interactions by appeal to the direct perception of others' intentions through their expressions and bodily movements. Tamer Soliman and Art Glenberg, in perhaps the most speculative chapter of the book, outline an account of how culture might emerge from a web of motor programs, perceptual schemata, and emotional reactions that arise as bodies act in response to each other and their environments. Joint action, they argue, provides opportunities for sensorimotor bonds that create a distinction between in- and out-groups, the basis for culture. This topic is rounded off with Brendan Strejcek and Chen-Bo Zhong's survey of embodied theories of morality. They reveal connections between moral judgments and emotions, such as disgust, that in turn reflect facts of embodiment. The work they describe shows a deep overlap between physical and moral domains, as when purity becomes associated with cleanliness, the color black with immorality, or fishy smells with suspicious behavior.

The closely related topic of emotion invites approach from a number of distinct embodied perspectives. Michelle Maiese treats emotions as enactive, echoing Di Paolo and Thompson's view of cognition as a kind of sense-making. For Maiese, bodily feelings play a role in generating meaning in organism-environment interactions, and she sees appraisal of situations and bodily processes as constitutively interdependent. Paula Niedenthal, Adrienne Wood, and Magdalena Rychlowska are interested in how people represent emotion concepts, and how people identify facial expressions as having particular emotional content. On their view, emotion concepts refer to forms of behavior, including facial expressions and gestures. Among the interesting evidence they cite are associations between the activation of particular facial muscles and the processing of nouns that suggest emotional content, as well as a degradation in the ability to process emotion words when activity in facial muscles is suppressed. Suzanne Oosterwijk and Lisa Feldman Barrett close out the theme of emotion with a discussion of how people come to understand emotions in others. They argue that our capacity to recognize others' emotions depends on the very same processes that produce emotional responses in ourselves. This view rests on a conception of emotions that sees them as states built upon sensorimotor and interoceptive responses of the body.

Michael Madary kicks off the study of awareness. His primary interest is visual consciousness. He describes the distinct contributions that enactive, embedded, and extended theories of vision make to an overall understanding of the sense of visual presence and provides a state-of-the-art survey of objections and responses to these approaches, clarifying the role of action in visual perception. Thomas Metzinger's studies of out-of-body experiences comprise some of the most intriguing work in embodied theories of awareness. His pursuit of an explanation of the phenomenology of selfhood – of the feeling of being an embodied self – has led to a series of experiments that induce out-of-body experiences in his subjects. In this chapter he describes three orders of embodiment that he believes to be critical components in a full account of self-awareness. Third in the area of awareness is Frédérique de Vignemont's answer to the question of how human beings attain awareness of their bodies as distinct single-bounded objects surrounded by space. She rejects sensorimotor accounts of awareness of bodily space, i.e. of where in space the parts of one's body are, defending instead a representationalist theory of bodily awareness. However, she endorses a sensorimotor approach to explaining a distinct phenomenon, namely the feeling of bodily presence that we possess when, for example, something brushes against our cheek, making us aware of the presence of our cheek.

Memory and attention are next on the list of cognitive functions that embodied cognition researchers have targeted. Katinka Dijkstra and Rolf Zwaan describe research that reveals a

number of interesting connections between memory and action. Memory, they argue, draws on the same neural resources that were activated in the original experience of which the memory is a trace. Thus, the neuroscience of memory shows the crucial role of simulating (or re-enacting) the actions and perceptions of the experience that constitutes the content of the memory. From this perspective, it's perhaps not surprising that memories are easier to recall when assuming the bodily positions and postures that were present during the remembered experience. Next, Michael Spivey and Stephanie Huettenlocher defend a conception of attention as an extended process, involving a perception-action loop that involves actions which redirect perception to unnoticed or new parts of the environment, which changes the nature of the stimulus reaching the perceptual organ, which leads to new actions, redirecting perception yet again, and so on. All parts of this loop, including the environment, are in their view constituents of attention. They contrast this model of attention to earlier ones that conceived attention as a simple filtering mechanism. John Sutton and Kellie Williamson close this topic with a discussion of embodied memory. They provide a useful survey of historical and current studies of various memory-related phenomena and explain the sense in which memory is an embodied skill. On their view, memory incorporates bodily experiences, and movements of the body contribute significantly to the triggering of particular memories, showing the body to be a vehicle of memory.

The final chapters in this part of the handbook discuss group cognition. Paul Smart examines information-processing loops that incorporate the World Wide Web, raising the possibility that cognition extends into the online world. He also describes new technologies that facilitate a blending of sensorimotor contact with Web-based information, revealing opportunities for cognitive enhancement, and blurring distinctions between online and offline activities. Gerry Stahl studies the interactions between members of online math teams as they interact to solve mathematical problems. He argues that the teams exhibit group cognition only when meeting three preconditions. They must demonstrate an extended sequential approach to the problem they examine, display persistent co-attention, and work with a shared understanding of the problem. Wrapping up this theme is Georg Theiner's chapter on varieties of group cognition. In an effort to operationalize the idea of group cognition, Theiner offers a taxonomy of distinct dimensions along which group tasks can be distinguished from each other. He pays special attention to the phenomena of group memory and group problem solving, comparing group performance to the performance of individuals and explaining the variables that seem to improve or degrade group performance.

The final part of the handbook serves as a matching bookend to the first part. Chapters 1 and 2 presented historical antecedents of embodied cognition, and Chapters 34 and 35 look to embodied cognition's future. Gary Hatfield's chapter begins with a question that has probably occurred to any reflective follower of recent trends in cognitive science: What is cognition? Is there a shared conception of cognition that unites the diversity of research programs represented in this book? If so, is it an understanding of cognition that members of the "standard" cognitive science community would recognize? Hatfield's answer to these questions begins with an examination of some prominent early work in cognitive science, especially Ulric Neisser's, before moving on to more contemporary literature including Jerry Fodor's influential defense of a language of thought and David Marr's theory of vision. Interestingly, Hatfield finds room for Gibson's ecological psychology within a computational and representational framework (but, significantly, one that is non-symbolic), challenging Michaels and Palatinus's claim that the ten commandments of ecological psychology that they described in Chapter 2 must be endorsed all or none. In another surprising turn, Hatfield presents Descartes, a punching bag for many in the field of embodied cognition, as an early advocate of embodied cognition, especially of

embodied memory. In the end, Hatfield settles on a description of cognition as that which produces intelligent behavior. Accordingly, he urges that cognitive scientists attend more closely to varieties of intelligent behavior, and suggests that investigations of the evolution of mind might provide a rich source of material for identifying and classifying intelligent behavior.

Last up is Michael Wheeler's chapter on the relationship between embodied cognition and traditional, or computational, cognitive science. His more particular focus is extended cognition, which he examines in part to determine whether, *qua* paradigm of embodied cognition, it demands a departure from the conventional commitments of cognitive science. As Wheeler sees matters, extended cognition remains consistent with the functionalist theory of mind that grounds traditional cognitive science, requiring for its investigation nothing in addition to the computational, representational resources that traditional cognitive science delivers. Rejection of traditional cognitive science, he contends, was motivated in large part by a perception among many researchers that computational theories of cognition found an insuperable obstacle in the so-called frame problem. However, he responds, the theoretical apparatus deployed by members of the embodiment community in an effort to overcome the frame problem fares no better. In cases of a draw, such as this one, the deciding factor ought to be conservatism. The methods and ontological commitments of standard cognitive science win out because of their proven track record. Notice, however, that this is not a denunciation of embodied cognition, but rather an effort to trim its more radical expressions so that it might fit into the more familiar clothing of traditional cognitive science.

PART I

Historical underpinnings

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PHENOMENOLOGY AND EMBODIED COGNITION

Shaun Gallagher

As this volume makes clear, research on embodied cognition draws from a number of disciplines and is supported by a variety of methodological strategies. In this chapter I focus on what phenomenology has contributed to our understanding of embodied cognition. I take “phenomenology” to mean the philosophical tradition initiated in the twentieth century by Edmund Husserl and developed by a variety of philosophers, including Martin Heidegger, Maurice Merleau-Ponty, Jean-Paul Sartre, Aron Gurwitsch, and numerous others. More recently phenomenologists following this tradition have been drawn into theoretical and empirical research in the cognitive sciences, and especially into discussions of enactive and embodied conceptions of the mind (e.g. Dreyfus, 1973, 2002; Gallagher, 2005; Gallagher and Zahavi, 2012; Thompson, 2007; Varela, Thompson, and Rosch, 1991). I’ll start by looking at some of the historical resources that define the phenomenology of the body. I’ll then consider how phenomenology, as a methodology, relates to scientific investigations of embodied cognition, and finally go on to identify some of the insights about embodied cognition that phenomenology provides.

Historical resources

An analysis of embodied aspects of perception and cognition can be found in Husserl’s early work. Husserl (1997) writes about the role of kinesthesia (movement sense) in perception. For example, since extraocular motor processes help to control where we look, kinesthetic feedback from that movement correlates with perception in the visual field. Extraocular processes, however, are embedded in a motor system that controls head movement, and general body posture. Accordingly, kinesthetic patterns more generally are activated in correlation with visual perception. More than that, visual objects activate the kinesthetic system in such a way that the positions and shapes of the objects are “con-figured” with potential bodily movements. This kind of analysis broadly prefigures the contemporary neuroscience of the pragmatic and affective resonance that occurs in our motor systems when we perceive objects within our manipulable area (instantiated in the activation of canonical and mirror neurons – see Rizzolatti *et al.*, 1988; Rizzolatti, Fadiga, Gallese, and Fogassi, 1996).

Husserl continues this analysis in several of his writings, but especially in *Ideas II* (1913/1989). There he develops the important phenomenological distinction between *Körper*, variously translated as the objective body or the body-as-object, and *Leib*, the lived body or body-as-subject.

In regard to the body-as-object we may distinguish between how the body is conceived by different kinds of knowledge – for example, objective and scientific knowledge – that one might have of the body, and more immediate experiences of the body when, for example, we reflectively focus on some body part. These different aspects of the body-as-object are included in what some theorists call the (long-term and short-term) body image (O’Shaughnessy, 1995) which encompasses perceptual, affective, and conceptual dimensions. In contrast, the body-as-subject refers to the perceiving (or experiencing) body, the agentive body that moves in action, where most of the experiencing is pre-reflective. In this regard, as I perceive the world around me, or as I engage in action, I do not experience my body as one object among others in the environment. At the same time I am not completely unaware of my position or my movement. In this notion of pre-reflective awareness of bodily position and movement (based not only on proprioceptive and kinesthetic processes, but also visual and tactile information) we have a prefiguring of Gibson’s (1979) notion of ecological perception. That is, when I perceive the world I also have an implicit awareness of my own position, posture, and movement.

Likewise, in Husserl’s notion of the “I can” we find a prefiguring of Gibson’s notion of affordances, and an enactive approach to perception. Husserl contends that as I perceive the objects around me, I perceive them in terms of the possibilities I have to interact with them. I see X not in purely objective or recognitional terms as the object X; rather I see it as something *I can* grab, or eat, or throw, or sit upon. These action possibilities are not cognitive additions to perception but are implicit in the way that I perceive the object – that is, implicit in the intentional structure of perception.

From these kinds of analyses we can see that, for Husserl, embodied aspects of experience permeate perception. Husserl’s analyses of the intentionality of other cognitive acts, such as memory and imagination, however, also show the relevance of these embodied aspects. Thus, in his analysis of memory, he suggests that episodic memory involves a re-enactment of past perception, which includes the original intentional structure of that perception, and thus the various bodily aspects implicit in that structure. Remembering my past actions, for example, involves a making present again, although in a modified sense (Husserl uses the term *Vergegenwärtigung*), of perceptual experience. Again we can note the consistency between this phenomenological account and contemporary scientific accounts of memory (see e.g. Schacter *et al.*, 1996).

Merleau-Ponty picks up where Husserl left off. Merleau-Ponty, however, was also influenced by Heidegger, and by his own readings in developmental psychology, psychiatry, and neurology. Heidegger (1962) has little to say about the body *per se*, but he does provide an influential account of a particular way of being-in-the-world that is implicitly embodied. His notion of the ready-to-hand (*Zuhanden*) involves a pragmatic conception of our ordinary stance towards the world. Not unlike Husserl’s notion of the *I can* or Gibson’s later notion of *affordance*, Heidegger pictures our human existence (*Dasein*) as pragmatically involved in tasks where tools are incorporated into our action intentionalities – experientially transparent extensions of our bodies as we engage in the world. This analysis figures prominently in Hubert Dreyfus’s work on embodied coping and expertise (Dreyfus, 2000).¹

Of all the phenomenologists, however, Merleau-Ponty is best known as the philosopher of embodiment. He was able to integrate his study of psychology and neurology into his phenomenology of perception where the notions of lived body and body schema play a central role. For Merleau-Ponty (2012) the body is the perceiver, and perception involves both sensory and motor processes. He provides an analysis of kinesthesia, phantom limbs, and other such topics by drawing heavily and with a critical eye on the neuroscience/neurology and psychology of his time. In a central chapter of his *Phenomenology of Perception*, he introduces the concept of the body schema, which he takes from the work of Henry Head, and then famously uses the

pathological case of Schneider to rework the concept. He distinguishes the spatiality of the surrounding environment from the spatiality of the body, organized in a proprioceptive order where my hand is not next to me in the same way that the cup is next to me. “My entire body is not for me an assemblage of organs juxtaposed in space. I hold my body as an indivisible possession and I know the position of each of my limbs through a body schema [*un schéma corporel*] that envelops them all” (Merleau-Ponty, 2012, pp. 100–1). The body schema is ambiguous since it is activated when I engage in intentional action but also seems to operate on its own in a way that is not explicitly under my control. The body schema is not something produced by an association of partial images or sensations, but a whole which governs the parts – it’s the law or principle of movement rather than the immediate product of movement. It dynamically organizes bodily movement in terms of the organism’s projects – or the subject’s actual or possible tasks. The spatiality of the body, then, is not an objective spatiality measurable by a ruler, but a “spatiality of situation” in which the body and the world form a practical system (*ibid.*).

A patient of Gelb and Goldstein, Schneider, who suffered extensive brain damage from a war wound, is unable to follow a specific instruction to move in a certain way. He is not able to flex his arm if he is commanded to do so, for example. Yet he is able to move in a voluntary way to accomplish everyday goals and work actions. He has a problem with what Goldstein called “abstract” movement, but not with “concrete” movement. His body-schematic control of a contextualized action works without a problem; but his attempt to move to order involves him attending to the body as an object and organizing it into a position defined in the axes and coordinates of objective space. One thing Merleau-Ponty’s long and detailed analysis of this complex case shows is that subjects without Schneider’s problems are able to deal with possible action, and not just action that is driven or elicited by the concrete environment – although this too is extremely important for many of our actions.

Merleau-Ponty takes over Goldstein’s (1971) distinction between grasping (which is “concrete”) and pointing (which is “abstract”/categorical). These distinctions remain somewhat ambiguous, however, so that even normal grasping capacity may require the categorical attitude (Goldstein, 1971, pp. 279–80). Despite this ambiguity, the distinction between grasping and pointing has been taken by some phenomenologists to mean that concrete behavior (e.g. grasping) is more basic (it survives certain pathologies where pointing does not), and that it characterizes our normal motor intentionality in its non-representational, non-conceptual form (e.g. Kelly, 2000, 2004). In pathological cases, like Schneider, for example, these two capacities can come apart. There are several important qualifications to be made here, however. First, the extent of Schneider’s brain damage remains unclear, so we have an incomplete picture of his pathologies (see Jensen, 2009). Second, we need to carefully distinguish between normal functions that manifest themselves more clearly in pathological cases, and functions that emerge as compensatory within the pathology (Marcel, 2003). Kelly assumes that Schneider’s intact concrete capacities are normal, but this may be unwarranted. Finally, there are various kinds of pointing: non-communicative pointing (touching *X* in an experimental situation); communicative (deictic) pointing; imperative pointing (to something I want); and declarative pointing (to call another’s attention to something). Moreover, in different pathologies communicative pointing and gestures may be intact when concrete grasping and non-communicative pointing are impaired (see e.g. Cole, Gallagher, and McNeill, 2002).

Jean-Paul Sartre (1956) introduced a different consideration by distinguishing between the body-for-itself (that is, the body-as-subject) and the body-for-others. This integrates an important dimension of intersubjectivity into the analysis of the body. In this regard, Merleau-Ponty emphasized the notion of intercorporeity – a kind of intertwining of two embodied subjects in perceptual and interactive contact, a concept that supports more recent discussions of interaction

in social cognition (e.g. De Jaegher, Di Paolo, and Gallagher, 2010). For Merleau-Ponty, “other minds are given to us only as incarnate, as belonging to faces and gestures” (1964, p. 16). For Sartre, however, the body-for-others is first of all an observed object – it falls under the gaze of the other person and in most cases is objectified or reified. The other sees me first as an object, and this defines the initial encounter that I then have to work through in my intersubjective dealings with that other. Importantly, this adds a certain dimension to the subject’s experience of her own body. Not only is my body seen by the other; it is experienced by me as seen by the other. This initiates an exterior perspective that I have on myself, and contributes to the constitution of an objective self.

Phenomenology in science

In scientific contexts the concept of phenomenology is not usually taken in the strict or formal sense defined by the philosophical phenomenological tradition. In this less formal sense, phenomenology still has an important role to play in studies of embodied cognition and bodily action. In this context, one might think that phenomenology, on its own, is limited to an analysis of the consciousness of the body (the way that we are aware of the body) since strictly speaking phenomenology is not able to penetrate beyond our experience of how things seem to us – the way the world appears, or the way one’s body appears in consciousness. While phenomenology can certainly provide this kind of analysis, it can also go beyond it in at least two ways.

First, in the phenomenological analysis of action, for example, I can discover, in a negative way, what I either *do not* or *cannot* experience. For example, when I reach to grasp a cup I am not aware of the precise shaping of my grasp, which, on the basis of certain subpersonal processes and my pragmatic relation to the particular object in the environment, is different from the detailed shape of my grasp when the object is much smaller or much larger, or shaped differently, or positioned differently, etc. This shaping of the grasp happens in a non-conscious way. Although I am not aware of how this shaping of grasp takes place, and usually am not even aware of the precise details of my finger positions as I grasp, I can discover this lack of awareness phenomenologically in reflection. That is, I can discover that I am not aware of the shaping of my grasp in the normal course of such action. More generally, in this negative way, I can reflect on elements of body-schematic motor control and affective factors that remain non-conscious and that modulate perception, attention, and action.

One might argue that behavioral studies can already tell us this. But in some important way this kind of negative phenomenology is an initial part of any behavioral study of this sort. If, for example, a scientist were studying for the very first time the simple action of reaching to grasp something, it would be important to know what the agent is conscious of during the action. Is the agent entirely unconscious of everything pertaining to the action; or is the agent entirely conscious of all aspects of her movement? When the agent reports that she is or is not conscious of a particular aspect of the action (if indeed she is asked) she is giving a phenomenological report (and with some training she may be better able to say what she is or is not conscious of). If the agent is not asked to provide such a report, there is likely some implicit or explicit assumption made by the behavioral scientist based on her own experience, or on previous empirical knowledge about how such things work. Even in the latter case, there is still some phenomenological fact of the matter, established in previous work and likely built into the design of the experiment. More generally, questions about what a subject is conscious of or not conscious of, what they know or don’t know about the experiment, whether they are focused or not focused on what they are asked to focus on, etc., are important ones in many behavioral experiments.

Second, even if many of the effects of bodily processes on cognition happen on the sub-personal or neuronal level, phenomenology can still be relevant to working out a causal explanation. Since the investigation of subpersonal processes is often meant to be explanatory for cognitive operations that also have a person-level dimension – assuming that remembering, imagining, deciding, solving problems, dreaming, etc., are in some regards part of a person's conscious experience – it seems important to understand the nature of the person-level explanandum to even know what type of subpersonal processes to look for, or how such processes can be explanatory. Without the phenomenology, in fact, neuroscience would be hard pressed to know what to look for; it would be working in the dark.

Consider the study of phantom limbs. Whether the neuroscientist discovers a neuromatrix involved in the phenomenal presence of the limb (Melzack, 1990), or that neural plasticity is responsible for phantom pain, such explanations would make no sense at all without some reference to the subject's experience. Likewise for any number of pathological or experimentally induced phenomena – somatoparaphrenia, anarchic hand syndrome, delusions of control, rubber-hand illusion, whole-body displacement, the Pinocchio effect, etc.

To be clear, there is not necessarily a one-to-one correlation between the phenomenology and specific brain processes. But cognition researchers are able to point to specific activated brain areas only in reference to person-level phenomena. To put this more strongly, it is not only that what happens on a phenomenologically accessible personal level can give us some clue to what may be happening on the subpersonal level, but that it may count as part of the explanation of subpersonal processes. The explanation has to go at least two ways: bottom-up and top-down. A cognitive neuroscientist who explains that neurons in area F5 are activated, must give some indication of what this activation correlates with on the personal level of experience or behavior. In regard to cognitive neuroscientific methodology, if subjects are not in a specific personal-level situation (e.g. engaged in an intentional action, or watching another person engage in an intentional action) there is no expectation that specific neurons in area F5 will activate. Neuroscientists thus need to appeal to personal-level practices and phenomenological experiences in setting up their experiments, and in many cases the only way to define the explanandum is in terms of phenomenology. In any particular case, if the neuroscientist is investigating brain processes that correlate with *X* (on an experiential or behavioral level) she cannot simply depend on a wild guess about what the experience of *X* is or what behavioral situations might elicit it.

What does phenomenology tell us about embodied cognition?

Numerous phenomenologists have indicated that there is a sense of “mineness” or “ipseity” built into every experience. This is sometimes called the sense of ownership (SO), where ownership means not some external relation of *having* something (as in ownership of property), but signifies the intrinsic “ownness” or mineness of experience, an aspect of the experience that makes it subjectively *my* experience. SO, as such, holds not only with regard to experiences of my body or my body parts, e.g. when I reach and grasp something, the sense that it is *my* arm that is reaching and *my* hand that is grasping, but also in regard to my experiences of self-movement and action – SO not only for my arm, but also for my action. SO is directly tied to the phenomenological idea of pre-reflective self-awareness, i.e. when we consciously think, or perceive, or act, we are pre-reflectively aware that we are doing so, and this pre-reflective awareness is something built into experience itself, part of the concurrent structure of any conscious process.

Pre-reflective self-awareness, however, also involves a sense of agency (SA), which is conceptually distinct from SO (Gallagher, 2000). SA can be defined as the pre-reflective experience

that I am the one who is causing or generating a movement or action. The phenomenological distinction between SA and SO can be easily understood in the experience of involuntary movement. If someone pushes me from behind, I experience the initial movement as something happening to me, as something that I am experiencing, and so have an experience of ownership for the movement. I do not claim that it is someone else who is moving, since I have an immediate sense that I am the one moving. At the same time, however, I can say that I have no experience of self-agency for this movement. I did not cause it; someone else pushed me. So in the case of involuntary movement (as well as in reflex movement) SA and SO come apart. In the case of voluntary action, on the other hand, they seem tightly fitted and indistinguishable in pre-reflective experience.

Neuropsychologists have found this distinction useful for clarifying their studies of agency and perceptual illusions, for example, the rubber-hand illusion. Experimenters have tried to identify the neural correlates for SA. Let's think again about involuntary movement. In the case of involuntary movement there is SO for the movement but no SA. The neuroscience suggests that awareness of my involuntary movement is generated in reafferent sensory feedback (visual and proprioceptive/kinesthetic information that tells me that I'm moving). In the case of involuntary movement there are no initial motor commands (no efferent signals). Thus, it seems possible that in both involuntary and voluntary movement SO is generated by sensory feedback, and that in the case of voluntary movement SA is generated by efferent signals (Tsakiris and Haggard, 2005; Tsakiris, 2005)

On this view SA is conceived as generated in motor-control-related brain processes. But this may not be the whole story. SA, in addition to involving a sense of controlled embodied movement, involves a sense of controlling events in the external world. We can therefore distinguish between an experience of agency generated in motor control processes, and an experience of agency associated with perceptual monitoring of what one actually accomplishes by the action. Both of these aspects, the *motor control aspect* (the sense that I am causing or controlling my bodily movement, linked to efferent processes) and the *intentional aspect* (what gets accomplished, or fails to get accomplished, by the action, provided by perception), enter into SA. As Haggard (2005) shows, there is a confirmatory consistency between the neuroscience and the phenomenology. That is, phenomenologically one can make the same distinctions between SA taken as a sense of bodily control, and SA taken as a sense of controlling what one accomplishes in the world (Gallagher, 2007).

This distinction, however, has been confused in experimental literature. For example, in an fMRI experiment conducted by Farrer and Frith (2002), and designed to find the neural correlates of SA, subjects are asked to manipulate a joystick to drive a colored circle moving on a screen to specific locations on the screen. In some instances the subject causes this movement and in others the experimenter or computer does. The subject is asked to discriminate self-agency (when they feel they are in charge of the movement) and other-agency (when they feel the other person is in charge of the movement). Citing the distinction between SA and SO, Farrer and Frith associate SA with the intentional aspect of action, i.e. whether I am having some kind of effect with respect to the goal or intentional task (or what happens on the screen). Accordingly, they claim that SO ("my hand is moving the joystick") remains constant while SA (based on the intentional aspect) changes. When subjects feel that they are not controlling the events on the screen, there is activation in the right inferior parietal cortex and supposedly no SA for the intentional aspect of the action. When the subject does have SA for the action on the screen, the anterior insula is activated bilaterally.

Although Farrer and Frith clearly think of SA as something tied to the intentional aspect of action and not to mere bodily movement or motor control, when it comes to *explaining why*

the anterior insula should be involved in generating SA, they frame the explanation entirely in terms of motor control. In the protocol of the experiment, and then in the explanation of the results, the distinction between the two aspects of SA (motor control aspect and intentional aspect) gets lost. In such a case, phenomenology can be put to good use. Closer attention to the phenomenology of agency could help to clarify the distinction between the intentional aspect and the motor aspect of agency, a distinction that can easily get confused in the neurological explanation.

Phenomenologists can also show that there is more to SA than the pre-reflective elements delineated here. In actions that involve reflective deliberation or retrospective evaluation, these more reflective aspects of action, which may also bring into play social norms and forces that are not reducible to processes confined to individual brains, may enter into the experience of agency (Gallagher, 2010). In this regard, phenomenology tends to support a non-reductionist approach to the naturalistic study of human agency, and to regard SA as complex, involving both pre-reflective and reflective aspects.

How much detail can phenomenology explicate within the pre-reflective SA? One might be able to make legitimate conceptual or theoretical distinctions between “awareness of a goal, awareness of an intention to act, awareness of initiation of action, awareness of movements, sense of activity, sense of mental effort, sense of physical effort, sense of control, experience of authorship, experience of intentionality, experience of purposiveness, experience of freedom, and experience of mental causation” (Pacherie, 2007, p. 6). The question is whether all of these distinctions show up as such in the actual first-order phenomenology. Might they not be the product of theoretical reflection on the first-order phenomenology? As I engage in action I may not experience a difference between my sense of effort and my sense of control, although I can certainly make that distinction in my reflective (retrospective) consideration of my action. The distinctions may show up clearly at the level of my retrospective attribution, but may be entirely lost in my immersed and pre-reflective SA. My awareness of *what* I am doing and *that* I am doing it is usually struck at the most pragmatic level of description (“I’m getting a drink”) rather than at a level that distinguishes between the action and my agency, or within the action between the goal and the means, or within agency between intentional causation, initiation, and control.

Considerations about SO and SA enter into a phenomenological analysis of self-consciousness – specifically, a minimal, pre-reflective embodied self-consciousness that is more basic than reflective, conceptual aspects of self-consciousness. This basic self-awareness is nonetheless complex since it involves distinctions between self and non-self, as well as SO and SA; but it is also fragile since aspects of SO and SA may be disrupted or deleted in certain pathologies or experimental situations. The complex pre-reflective SA may disappear or be disrupted in delusions of control, or conditions such as anarchic hand syndrome, where one hand seems to do intentional actions that are not under the subject’s control. Likewise, SO may be modulated or may disappear for specific actions or limbs, as in somatoparaphrenia following stroke (where a patient may claim that her left arm does not belong to her), or in experiments such as the rubber-hand illusion, where certain visual and tactile stimulations can lead to the feeling that a rubber hand is actually part of one’s body.

As Sartre indicated, however, phenomenology can tell us something not just about one’s own body and self-consciousness, but can also contribute to an account of embodied social cognition. In Sartre’s terms, the body is not only *for me*, it is also *for others*. Following certain aspects of Husserl’s and Merleau-Ponty’s analysis, one can develop the notion of “intercorporeity” as the basis of an embodied account of intersubjective interaction that is highly consistent with both developmental science and recent discoveries in social neuroscience. In this

respect one can point to aspects of embodied and enactive perception of the other's movements, postures, facial expressions, gestures, and actions that contribute to an underpinning of our understanding of others in the rich emotional, social, and pragmatic contexts of everyday life. Our capacities for joint attention and joint action are bodily capacities that develop early in infancy. We learn to move in certain ways and to engage in pragmatically relevant actions from our interactions and observations of how others move and act. Bodies, and not just brains and minds, appear on either side of these interactive processes. In these relations, bodies are not cold reified objects, but affectively rich, living subjects without which we would have a difficult time explaining love, passion, desire, and the various drives that move us toward or away from one another.

More generally, phenomenology points to the importance of affect, in addition to the various sensorimotor contingencies normally emphasized by enactive accounts of perception (as in Noë, 2004). Any account of embodied (or enactive) cognition that focuses exclusively on sensorimotor components of perception or action, and ignores the realm of affect, provides an incomplete story since one also needs to account for motivational pull in one direction or another, or a sense of pertinent affective contingencies (Bower and Gallagher, 2013). Bodily affect significantly contributes to (either limiting or enabling) our contact with the world in our perceptually operative attentive outlook, in defining our perceptual interests, as well as in social perception. Affects are not restricted to the domain of phenomenal consciousness, although they may certainly have an effect on what experience feels like. Affects may or may not reach the threshold of conscious awareness. Consider the case of boredom (see Heidegger, 1995). Boredom is more than potentially related to action, in the case where we might try to overcome boredom. More importantly, boredom already modulates one's viewing or listening behavior, and it shows up in the way one arranges one's body, perhaps without even noticing, in a bored manner; or, in the way one begins to fidget, widen one's eyes, give vent to an exasperated breath, etc. Such bodily expressions are moments of the affective phenomenon of boredom – part of the pattern of boredom that can be observed in bodily behavior. In boredom one finds oneself immediately embodying a certain stance towards one's situation, a pull that resonates with and perhaps already prepares, any further course of action.

Affect is deeply embodied. Affective phenomena like fear, for example, have been shown to be determined by circulatory functioning – the heartbeat influences how and whether fear-inducing stimuli (images of fearful faces, in the reported experiments) are processed (Garfinkel, Minati, and Critchley, 2013). Fearful stimuli are more easily recognized when the heart contracts in a systole phase, and are perceived to be more fearful than when presented in a diastole phase. That is, the fact that we are flesh and blood creatures equipped with beating hearts, rather than brains in vats, explains in part why we have the experiences that we do. We could point to many other examples of how the affective condition of the body shapes cognition. For example, we perceive features of the world according to whether we are fatigued or carrying weight (see e.g. Proffitt, Stefanucci, Banton, and Epstein, 2003). Hunger can shape, and perhaps even distort, judgment and rational decision. For example, whether a judge is hungry or satiated may play an important role in her decisions about sentencing (Danziger, Levav, and Avnaim-Pesso, 2011). These empirical studies make explicit and provide scientific weight to what phenomenology discovers as affects and motivations implicit in pre-reflective experience.

In summary, phenomenology can point to a number of aspects of experience that demonstrate the embodied nature of cognition, including basic perceptual processes. The phenomenological analyses of movement and action, self-consciousness, intersubjectivity, and affect constitute only a limited number of issues in a broader range of embodied phenomena that are open to phenomenological investigation and confirmation in empirical scientific studies.

Note

- 1 Dreyfus was also influenced by his reading of Merleau-Ponty (e.g. Dreyfus, 2002). On a historical note, Aron Gurwitsch was also an important connection. Gurwitsch, influenced by both Husserl and Heidegger, and by his reading of Gestalt psychology, lectured in Paris in the 1930s (some of these lectures were attended by Merleau-Ponty) before arriving in the United States where he spent time on the faculty at Harvard and Brandeis and engaged in discussions with Samuel Todes. Todes produced a dissertation entitled *The Human Body as Material Subject of the World* at Harvard the year before Dreyfus finished his PhD there, and Dreyfus later organized the republication of Todes's dissertation as *Body and World* (2001).

References

- Bower, M., and Gallagher, S. (2013). Bodily affects as prenoetic elements in enactive perception. *Phenomenology and Mind*, 4(1), 78–93.
- Cole, J., Gallagher, S., and McNeill, D. (2002). Gesture following deafferentation: A phenomenologically informed experimental study. *Phenomenology and the Cognitive Sciences*, 1(1), 49–67.
- Danziger, S., Levav, J., and Avnaim-Pesso, L. (2011). Extraneous factors in judicial decisions. *Proceedings of the National Academy of Sciences of the United States of America*, 108(17): 6889–92.
- De Jaegher, H., Di Paolo, E., and Gallagher, S. (2010). Does social interaction constitute social cognition? *Trends in Cognitive Sciences*, 14(10), 441–47.
- Dreyfus, H. (1973). *What computers can't do*. Cambridge, MA: MIT Press.
- (2000). Could anything be more intelligible than everyday intelligibility? Reinterpreting Division I of *Being and Time* in the light of Division II. In J. Faulconer and M. Wrathall (Eds.), *Appropriating Heidegger* (pp. 155–70). Cambridge: Cambridge University Press.
- (2002). Intelligence without representation – Merleau-Ponty's critique of mental representation. *Phenomenology and the Cognitive Sciences*, 1, 367–83.
- Farrer, C., and Frith, C. D. (2002). Experiencing oneself vs. another person as being the cause of an action: The neural correlates of the experience of agency. *NeuroImage*, 15, 596–603.
- Gallagher, S. (2000). Philosophical conceptions of the self: Implications for cognitive science. *Trends in Cognitive Science*, 4(1), 14–21.
- (2005). *How the body shapes the mind*. New York: Oxford University Press.
- (2007). The natural philosophy of agency. *Philosophy Compass*, 2(2), 347–57.
- (2010). Multiple aspects of agency: New ideas in psychology (April). Retrieved from <http://dx.doi.org/10.1016/j.newideapsych.2010.03.003>
- Gallagher, S., and Zahavi, D. (2012). *The phenomenological mind* (2nd ed.). London: Routledge.
- Garfinkel, S., Minati, L., and Critchley, H. (2013). Fear in your heart: Cardiac modulation of fear perception and fear intensity. Poster presented at the British Neuroscience Association Festival of Neuroscience, 8 April.
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton-Mifflin.
- Goldstein, K. (1971). Über Zeigen und Greifen. In A. Gurwitsch, E. M. Goldstein Haudek, and W. E. Haudek (Eds.), *Selected Papers/Ausgewählte Schriften*. The Hague: Martinus Nijhoff.
- Haggard, P. (2005). Conscious intention and motor cognition. *Trends in Cognitive Sciences*, 9(6), 290–95.
- Heidegger, M. (1962). *Being and time* (J. Macquarrie and E. Robinson, Trans.). London: SCM.
- (1995). *The fundamental concepts of metaphysics: World, finitude, solitude* (W. McNeill and N. Walker, Trans.). Bloomington: Indiana University Press.
- Husserl, E. (1913/1989). *Ideas pertaining to a pure phenomenology and to a phenomenological philosophy, second book: Studies in the phenomenology of constitution* (R. Rojcewicz and A. Schuwer, Trans.). Dordrecht: Kluwer Academic Publishers, 1989.
- (1997). *Thing and space: Lectures of 1907* (R. Rojcewicz, Trans.). Dordrecht: Kluwer Academic Publishers.
- Jensen, R. T. (2009). Motor intentionality and the case of Schneider. *Phenomenology and the Cognitive Sciences*, 8, 371–88.
- Kelly, S. D. (2000). Grasping at straws: Motor intentionality and the cognitive science of skilled behavior. In M. Wrathall and J. Malpas (Eds.), *Heidegger, coping, the cognitive sciences: Essays in honor of Hubert L. Dreyfus* (Vol. 2, pp. 161–77). Cambridge, MA: MIT Press.
- (2004). Merleau-Ponty on the body. In M. Proudfoot (Ed.), *The philosophy of the body* (pp. 62–76). London: Blackwell.

- Marcel, A. J. (2003). The sense of agency: Awareness and ownership of actions and intentions. In J. Roessler and N. Eilan (Eds.), *Agency and self-awareness* (pp. 48–93). Oxford: Oxford University Press.
- Melzack, R. (1990). Phantom limbs and the concept of a neuromatrix. *Trends in Neuroscience*, 13, 88–92.
- Merleau-Ponty, M. (1964). *Sense and non-sense* (H. Dreyfus and P. A. Dreyfus, Trans.). Evanston, IL: Northwestern University Press.
- (2012). *Phenomenology of perception* (D. A. Landes, Trans.). New York: Routledge.
- Noë, A. (2004). *Action in perception*. Cambridge, MA: MIT Press.
- O’Shaughnessy, B. (1995). Proprioception and the body image. In J. Bermúdez, A. J. Marcel, and N. Eilan (Eds.), *The body and the self* (pp. 175–203). Cambridge, MA: MIT Press.
- Pacherie, E. (2007). The sense of control and the sense of agency. *Psyche*, 13(1). Retrieved from <http://psyche.cs.monash.edu.au/>
- Proffitt, D., Stefanucci, J. Banton, T., and Epstein, W. (2003). The role of effort in perceiving distance. *Psychological Science*, 14(2), 106–12.
- Rizzolatti, G., Camarda, R., Fogassi, L., Gentilucci, M., Luppino, G., and Matelli, M. (1988). Functional organization of inferior area 6 in the macaque monkey, II: Area F5 and the control of distal movements. *Experimental Brain Research*, 71, 491–507.
- Rizzolatti, G., Fadiga, L., Gallese, V., and Fogassi, L. (1996). Premotor cortex and the recognition of motor actions. *Cognitive Brain Research*, 3, 131–41.
- Sartre, J.-P. (1956). *Being and nothingness: An essay on phenomenological ontology* (H. E. Barnes, Trans.). New York: Philosophical Library.
- Schacter, D. L., Reiman, E., Curran, T., Yun, L. S., Bandy, D., McDermott, K. B., and Roediger, H. L. (1996). Neuroanatomical correlates of veridical and illusory recognition memory: Evidence from positron emission tomography. *Neuron*, 17(2), 267–74.
- Thompson, E. (2007). *Mind in life: Biology, phenomenology, and the sciences of mind*. Cambridge, MA: Harvard University Press.
- Todes, S. (2001). *Body and world*. Cambridge, MA: MIT Press.
- Tsakiris, M. (2005). On agency and body-ownership. Paper presented at Expérience Subjective Pré-Réflexive et Action (ESPRA) Conference, CREA, Paris, December.
- Tsakiris, M., and Haggard, P. (2005). The rubber hand illusion revisited: Visuotactile integration and self-attribution. *Journal of Experimental Psychology: Human Perception and Performance*, 31(1), 80–91.
- Varela, F., Thompson, E., and Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.

2

A TEN COMMANDMENTS FOR ECOLOGICAL PSYCHOLOGY

Claire F. Michaels and Zsolt Palatinus

The ecological approach to perception and action evolved in the 1950s and 1960s, and major principles had been outlined by the time of the publication of J. J. Gibson's *The Senses Considered as Perceptual Systems* in 1966: ecological optics, invariants, exploration, direct perception, affordances, the education of attention, and the intimacies of perception and action, and of organism and environment, to name a few. In the intervening half century, these concepts have been experimented on and elaborated, and three new, related emphases have gained prominence: a concern with the coordination of action, adoption of the dynamical systems perspective, and embrace of what has been termed *physical psychology*, the attempt to make psychology continuous with physical science. Ecological psychology is arguably the original embedded, embodied cognition, so as the field that bears those names moves forward, the ecological approach should remain a valuable touchstone for evaluating principles, concepts, and theories.

In this chapter, we express the various historical and modern threads of ecological psychology as ten commandments. Obviously there are no “official” ten commandments that serve as the final authority for evaluating constructs or tools. The ones here are the result of a self-imposed intellectual exercise. It is with mixed feelings that we adopt the label “ten commandments.” The danger is that it will bolster the view held by some that ecological psychologists—Gibsonians—are more like religious fanatics than the conservative, open-minded scientists that we are. We brave that danger to make the point that just as observant Jews and Christians ought not pick and choose which Commandments they follow, advocates of ecological psychology (or of genuinely embedded and embodied cognitive science) should see our commandments as a package deal. Some psychologists select their principles and concepts cafeteria-style, adopting ideas they like and leaving others behind, and even declare that being eclectic is a virtue. Unfortunately, the major principles of ecological psychology are deeply connected and intertwined. To subscribe to some and discard the others always entails contradiction.

There are two more preliminaries before the enumeration begins. First, note that the chapter is global and intuitive, rather than detailed and precise. It would take several hundred pages to include details, cite relevant research, and identify variations on themes. Second, we will use the outfielder problem to illustrate various ideas, so we start with presenting the problem, which also can serve as a quick diagnostic test of how ecological one is.

The outfielder problem

The outfielder problem—how a centerfielder, say, can catch a ball that is hit precisely in the sagittal plane—brings home various emphases in the ecological approach. Assuming that the problem and its solution are not too old hat, trying to formulate a solution is a useful diagnostic tool for identifying one's own (perhaps tacit) theories of perception and or action. We ask the reader to submit to this test: think through how you believe the outfielder gets to the right place at the right time to catch the ball. We can keep it simple: one-eyed and deaf outfielders can catch balls, and at 100 meters, optical expansion of the image of a just-hit baseball is below threshold. Go!

The usual response is that the outfielder perceives the initial part of the trajectory, extrapolates that trajectory to estimate the time and place of the upcoming landing, and runs to that place by that time. The explanatory details vary from person to person: about the optical pattern that informs the perception of early trajectory, for example, or about how extrapolation operates (e.g. what is stored in memory and how the right trajectory is recognized or computed). If accounting for these details becomes the scientist's goal, the enumerated steps (information detection, pattern recognition, extrapolation, and action planning) become *the* constructs and processes that the theorist tries to embed and embody. However, as we shall see, it would already be too late to come to a good understanding of catching. Notice a few things about the account. The problems of perception and action are handled separately and sequentially, with the perceptual intermediaries including perceived trajectory, perceived (extrapolated, or inferred) landing time and landing place. Further, the to-be-perceived quantities dictate the kind of optical information one should look for—presumably the catcher needs information about both spatial and temporal components.

A more ecological solution to the outfielder problem, and for current purposes, we lump a number of related theories together, is that outfielders do not perceive trajectories, make predictions about when and where, and then act. Instead they run in such a way as to create an appropriate optical pattern. For example, the Chapman strategy (1968) proposes that a fielder runs so as to keep the rate of change of the tangent of the optical angle of the ball constant. The goal, to oversimplify, is to bring optical acceleration to zero and keep it there. This strategy puts the eye and the ball on intersecting paths; the catcher gets to the right place at the right time without perceiving the trajectory, or knowing either the time or place of intersection.

With these preliminaries in place, we now work through the major points of ecological science, organized into an admittedly arbitrarily ten commandments.

Commandment 1: thou shalt not separate organism and environment

Historically, psychology and philosophy have treated the skin as the boundary of their territory and thereby embraced an organism–environment (O–E) dualism. In O–E dualism, things inside the skin constitute one domain and things outside the skin another, and the two domains are approached independently. The alternative, ecological view is O–E mutuality—the O–E system is taken as the minimal unit of analysis in the behavioral and cognitive sciences and ought not to be disjointed into separate areas of inquiry.

One consequence of emphasizing O–E mutuality is for ontology. A characterization of the environment that is not mindful of the organism is left to classical physicists and is therefore defined and measured with the metrics of physics. Take the approaching fly ball. It has diameter, mass, velocity, spin, drag, etc., can be located in Cartesian coordinates of space and time,

and captured by Newtonian laws. Thus, anticipating a landing location requires either that the perceiver matches an input trajectory with stored trajectories, or applies some algorithm that approximates the physical laws. If, on the other hand, one attends to the O-E (catcher-ball) relation, problem and solution come together: the relevant optical information specifies how to modulate running so as to create and maintain a catcher-ball relation that puts them on a collision course.

Just as mid-twentieth-century biologists described and measured the environment as a home for life, ecological psychologists describe and measure the environment as a home for perceiving and acting. And just as we appreciate that ecologists' niches, dens, predators, and so forth constitute a bona fide ontology—real (objective, measurable) things that constitute the environment—so too are ecological psychologists' measurements of the environment (e.g. affordances); for both, the characteristics of the organism shape the property of the environment.

A number of key ecological concepts follow in whole or in part from the tenet of O-E mutuality. One is *affordances*, the possibilities for action that can be engaged in with respect to some object, event, place, etc. These are, as noted above, organism-referential properties of the environment, and because of that they are “ready-made” meaning. *Information*, too, is radically altered by a commitment to O-E mutuality. Descriptions and measurements of the energy patterns detected in perception are wrested from physics. Physical optics is replaced by ecological optics; physical acoustics is replaced by ecological acoustics, etc. The optical and acoustical structures relevant to perception and action cannot be captured in a one-size-fits-all description.

The new emphasis on environmental properties such as affordances does not mean that they are driving the show, as seems to be the inference that some thinkers draw when they liken ecological theory to behaviorism. Behaviorism did not at all respect O-E mutuality; it respected the skin boundary and sought explanations from the outside. As we shall see later, the ecological approach holds that intentions are central determinants of what is perceived and acted on.

Commandment 2: thou shall not take the name *information* in vain

The term *information* serves many masters in science and engineering, but ecological psychology singles out a particular meaning and uses it in this restrictive sense. Information is a pattern in space and time that specifies a state of affairs of the O-E system. By “specifies” is meant “relates to uniquely” or “relates to 1:1.” Specificity is an ecological, not a mathematical, concept; information is specific in the context of the O-E system. This means that information depends on global constraints (natural laws) and local constraints and circumstances. As an example, the law of universal gravitation captures the relation between masses, distances, and attractive force. The circumstances of the earth's mass and radius entail that a dropped object will accelerate at 9.8 meters/second per second. This local constraint, in turn, entails that in the optic array structured by the dropped object, the size and distance of the object, and its surrounds are specified. Local constraints contrived by a social and linguistic community can similarly constitute a basis for specification.

In addition to information-environment specificity, there is a second important specificity relation—that between perception and information. These two specificity relations together entail that perception is direct: because information is specific to an environmental state of affairs and perception is specific to the information, perception is specific to the environmental state of affairs – that is, direct.

Gibson's concept of information was a radical departure from the assumption of perception theorists from the Greeks through Helmholtz, Wundt, Titchener, the Gestaltists, and their

modern counterparts in cognitive (neuro)science. The Helmholtzian view assumes that the information to the senses is non-specifying—indeed, impoverished—and, therefore, requires that the perceiver engage in computational, comparative, and memorial processes that serve to embellish the input.

Commandment 3: thou shalt regard perception as the detection of information

This commandment is another way of formalizing and emphasizing the just-made point that perception is specific to information. The premise is simple: if information patterns specify the objects and events, then perception of those objects and events is simply a matter of detecting the information. The scientist who wants to understand perception of some property hypothesizes a candidate information variable and asks whether that variable accounts for the systematic variance in reports about perception. Given the apparent detection of a variable, one could then ask how detection is embodied, that is, how tissue might be arranged (by evolution or by learning) such that it detects or resonates to that information, in analogy to how an antenna might be transparent to certain wavelengths of electromagnetic energy but not to others, and how neural firing might resonate to the information, in analogy to a radio.

If a candidate variable does not account for the variance in reports or actions, it is rejected and the search for a successful candidate continues: failure of a variable is simply that; it is not disproof of direct perception. Relatedly, conclusions about the success of a variable should always be tentative. The “real” information might be a covariate of the successful candidate. Even so, there is never proof that felicitous perception or action hasn’t been achieved by virtue of computational and memorial processes. Dismissing this latter, conventional view must depend on other considerations, such as parsimony and which account has fewer unpaid loans of intelligence. In the ecological view, representation, calculation, comparison, and storage constitute such loans.

One might well ask why one variable and not some other is detected. This is by definition the realm of attention. How attention changes in learning is considered later in commandment 10.

Commandment 4: thou shalt not compute

The paradigmatic disembodied, unembedded device is the digital computer, which has served as a metaphor for a cognitive agent since the 1950s when flow charts were used to capture attentional and memorial processes. In distinguishing algorithmic and implementation levels, Marr (1982) sealed the deal on the legitimacy of disembodied computation. In the 1990s and 2000s, concern has shifted over to neurally embodied computation, but the computer metaphor—baldly, the consensual view of what the brain does—persists.

The alternative to a storage/comparison/computational metaphor is Runeson’s (1977) *smart perceptual device*. A smart perceptual device detects information; it does not detect low-level stimulus properties and from them compute other properties, or embellish them with additional information from memory. Runeson offered the planimeter as a metaphor to make the idea of a smart perceptual device more intuitive. The planimeter is a simple machine consisting of a fixed point, two jointed arms, and a calibrated wheel. The fixed point is planted, and the end of the distal arm is traced around the perimeter of a regular or irregular figure, causing the wheel to roll and skid. The difference between the readings on the wheel before and after the tracing specifies the area circumscribed by the perimeter. So for a rectangle, one could put the wheel to zero, trace the perimeter, and read off the area. Seeing that the wheel indicates area, and given

the conventional understanding that the area of a rectangle is the product of height and width, one might assume that the device measured the lengths, and multiplied. The construction of the planimeter, however, renders the outcome of the measuring act—tracing the perimeter—specific to area. The analogous expectation for a living system is that tissue is arranged (or, as we shall see later, rearranged) in a way that constitutes a smart device to register information.

Commandment 5: thou shalt not separate perception and action

What is perception for? Michael Turvey (1977) argued that perception served the needs of the action system. This view followed 150 years of concern with perception itself and relative inattention to action. More generally, he charged the psychological community to ask how action is coordinated, which, he claimed, was every bit as theoretically rich and worthy of study as perception. The research community (though arguably not the teaching community) has risen to Turvey's challenges, and issues of coordination and perception-action relations are now heavily investigated.

The concept of affordances already reflects the intimacy of perception and action. Organisms perceive actions that they can enter into with respect to other organisms, objects, events, and places. Affordances, however, are only part of the perception-action story. Two other aspects deserve mention. One is exploration: perceivers engage in a variety of acts that make information available—looking, sniffing, savoring—but it is the haptic sense that most obviously depends on exploratory movements, such as palpating, rubbing, hefting, wielding, etc. Second, performatory actions also reveal information appropriate for their own guidance. This is illustrated once again in fly-ball catching. Recall that the rate of change of the tangent of the optical angle of horizon and ball specifies whether the catcher's velocity is appropriate to guarantee intersection of the eye and ball trajectories, and thus the needed bodily acceleration. Accelerating forward in response to optical deceleration decreases that deceleration. When the optical deceleration is nulled, the eye and ball will be on intersecting trajectories. Optics structured by an act can serve to refine it.

Commandment 6: thou shalt have only one science before thee

What ought to be the relation between psychology and physical science? Are the phenomena of living and behaving systems so different from the phenomena of non-living and non-behaving systems that their respective sciences overlap little or not at all? The growing ecological view is more consonant with Iberall's dictum: "There is either one science or there is none." This commandment and the next two briefly address a scattering of themes that illustrate the idea of *physical psychology*, a budding discipline that exploits existing physical law and, where necessary, tries to crank up physical law to handle the phenomena of living and knowing. It emphatically does not try to crank *down* (reduce) the phenomena to a level that renders them explicable with physical law. One of the promising places to find lawfulness relevant for psychology is in the physics of self-organization.

One can think of scientific psychology as having the aim to explain the origins of the *patterns* over space and time that are manifested in experience and behavior: a sentence, guiding a car through traffic, a dance, groupings of Gestalt figures, groupings of people, personalities, seeing or recognizing a face, organization in recall—and the list goes on. We cannot think of an explanandum in psychology that is not some sort of pattern. There are three possible origins of patterns: other patterns, plans (algorithms, recipes, and blueprints), and self-organization. Only the last of these does not beg the question of origins. Using principles of self-organization to

move one's science forward is difficult. First, one needs to emphasize the dynamics of a system, its evolution over time. States and statistics computed about states will not do the job. One needs to capture changes in states. Second, one can look at how patterns arise in self-organizing physical systems, and ask whether the same or analogous processes are observed at the behavioral level. The paradigmatic example is that the same principles that capture the coupling of neighboring pendulums also capture interlimb coordination in humans, as when a person oscillates two fingers (Haken, Kelso, and Bunz, 1985). In both cases, only certain phase relations are stable. While the two coupling phenomena differ in a number of ways (e.g. mechanical vs. informational coupling), does one really need a new set of natural laws to explain the tendency for two fingers or limbs to oscillate in unison? And if it turns out that the limbs of two people show the same attraction (as it has turned out), does one need yet another natural law to explain the social version of the phenomenon? Instead, one ecological tack is to seek analogous phenomena in the physical world and to exploit the laws that explain them.

Commandment 7: thou shalt not steal intelligence

The just-mentioned prior patterns and plans as origins of to-be-explained patterns are obviously pure cheats as explanations; they just pass the buck. Less obvious are the theoretical concepts that ought to be considered members of this class of explanations: memory (representations) as the basis of recall and recognition, motor programs as the basis of coordination, priors in Bayesian learning, brain structures and firing patterns as the basis of patterns at the cognitive and behavioral levels, and so forth. Dennett (1978) used the term *loans of intelligence* to identify unaccounted-for knowledge that is needed to make cognitive systems work, but he was too nice. *Loan* connotes that it is understood as such, but it is usually the case that there is no acknowledgement either that the explanation is empty until the loan is repaid, or that repayment is even necessary. Until one can explain how the pre-existing pattern or recipe arose, the putative explanation is just a scientific shell game.

Commandment 8: thou shalt honor, exploit, and enlarge physical law

The careful expansion of physics needed to handle knowing and acting is exactly what Shaw and his colleagues are doing in *intentional dynamics* (e.g. Shaw and Kinsella-Shaw, 1988). Concepts in physics are generalized and enlarged to include intention and information (in the specificational sense). And just as physical dynamics captures constraints on the propagation of the path of a particle in space-time, intentional dynamics captures constraints, including intentional and informational constraints, on the propagation of an animal's path to a goal.

Ecological psychologists are sometimes charged with ignoring intention, and organism-based constraints, in general. In fact, ecological psychologists have had much to say about intention, though here there is only space for outlines and suggestions for important resources. First, one needs to distinguish the role intention plays from the origin of intention. As to the former, intentions are "exceptional boundary conditions" on the operation of physical laws (Kugler and Turvey, 1987). An intention harnesses a perceptual system to detect information appropriate to guide the deployment of metabolic resources. For the outfielder, the intention to catch a fly ball, for example, sets up the perception-action system in such a way that optical acceleration continually informs the deployment of metabolic resources to create forces at the foot that yield anterior or posterior locomotor acceleration. The intention to escape a lobbed grenade would entail other set-ups.

The origins of intention are more of a puzzle, but for us the best to-be-exploited insights derive from Iberall's concept of action modes (e.g. Iberall and McCulloch, 1969). Iberall argued that living systems comprise a small collection of limit-cycle oscillators that require a squirt of energy at regular, though not fixed, intervals. An organism needs to forage, eat, sleep, void, mate, etc. Each of these oscillators is marginally stable, and the winding down of a particular oscillator invites goal selection to restore the oscillation's amplitude. Our image of this is a juggler spinning an array of plates on sticks. As the rotational velocity of one plate decreases and it begins to wobble, the juggler must inject energy. The juggler thereby moves through a space of attractors whose strengths reflect current stability levels. These individual action cycles, together with the thermodynamic principles that capture their origins and maintenance, suggest where we might have to work to pay the cost of having intention play more than a descriptive, vitalistic role in science.

A closely related gambit of physical psychology and one that also has origins in thermodynamics is Iberall and Soodak's (1987) claim that the same (non-linear) laws apply at many scales. When there is flow through a system (e.g. heat through a spaghetti pot, water through a pipe, people evacuating a building or migrating across a continent, capital flowing through an economy) and the flow is higher than can diffuse through the medium, structures arise that increase the flow. A generalized Reynolds number predicts how the various patterns (convection cells, eddies, cliques, cities, wealth) arise. Nobody thinks that using these tools is easy, but surely it is a better way to start than by begging the question or proliferating whole sciences to explain patterns at each level. Honoring, exploiting, and enlarging physical law as it applies to behavioral and cognitive phenomena is, we think, a more promising strategy.

Commandment 9: thou shalt not make unto thee any mental image or likeness of anything

As noted earlier, philosophy and psychology have separated organism and environment and erected barriers between them (e.g. impoverished stimuli). For contact to be had with the environment, it had to be recreated (represented) in the brain or mind. Also deemed inexistent is the past, so the only means by which it can affect perception and action is also to have remnants of it stored away for later use. While philosophers have already acknowledged that some processes are less representation-hungry than others (Clark, 1997), the ecological commitment is to stand its ground: no representations, period.

The ecological take is that both perceptual and memorial representations are solutions to pseudo-problems arising from philosophical assumptions. Instead, perception is of the world—that is, direct—and learning does not involve storage. Certainly in the English lexicon the terms learning and memory go hand in hand, but we ought not to let language dictate theoretical entities. Is there some better way to understand the benefits of experience?

Michaels and Carello (1981, p. 78) tried to drive a wedge between learning and memory using an evolutionary metaphor: think of learning as we think of evolution.

If it is assumed that evolution leads to a *new* biological machine that is better suited anatomically and physiologically to the environment than its predecessors or extinct cousins, we might also assume that personal experiences lead to a new machine that is better suited to its particular, personal environment. It is better able to detect the environment's affordances. In this analysis, the consequence of personal experience is not that the old animal has new knowledge, but *that it is a new animal that knows better*.

It's time to graduate to an appreciation that the function of sensory and neural systems is to modulate animal actions at multiple timescales, in the case of humans, from milliseconds to decades. The fact that a clock might register an interval—even a long interval—between an environmental event and the subsequent modulation of behavior is no cause for panic.

The temporal evolution of any system—living or non-living, knowing or unknowing—is to be captured by laws and circumstances. This simple fact helps clarify a distinction between ecological and non-ecological approaches. Non-ecological approaches are inclined to emphasize circumstances over lawfulness: the current state of the brain or of cognitive structures—circumstances—serves as the primary explanation of phenomena. With this comes the view that the scientist's work ends with an account of circumstances that explains the variance in those phenomena. The ecological view is arguably more law-based, taking a longer view of the dynamics of cognition. Circumstances still play a critical role for the ecological approach. For example, we noted that information can derive specificity from terrestrial characteristics, but there is far more emphasis on uncovering a basis in natural law, for example, how surfaces structure light by reflection, how oscillators couple, or how flow through a system creates structure. In the final, upcoming commandment, we consider how lawfulness over a long timescale offers a different approach to learning than does storage.

Commandment 10: thou shalt change with experience

The alternative to the thesis that experience yields representations is that experience yields change—a different way of doing things. This final commandment addresses how that might happen.

E. J. and J. J. Gibson used the terms *differentiation* and *the education of attention* to capture learning, and E. J. Gibson devoted her distinguished career to addressing learning and development (E. J. Gibson, 1969). Differentiation was understood as becoming more able to distinguish among similar things. It involved detecting dimensions of difference, and becoming more attentive to distinctive features. Emphasizing such dissociation during the heyday of associationism, where meaning came from connecting things, created a storm of criticism, and a legendary battle ensued over “enrichment” theory. As forcefully as she argued against traditional views, E. J. Gibson's approach to learning, with its emphasis on features and its inclusion of representations, arguably did not do justice to J. J. Gibson's concept of information and to his theory of information pickup (as articulated in chapter 13 of J. J. Gibson, 1966).

Jacobs and Michaels (2007) have tried their hand at elaborating a theory arguably more consistent with J. J. Gibson's view; they termed it *direct learning*. Direct learning is in some ways at odds with the third commandment—that perceivers always exploit specifying information. This departure was motivated by observations that sometimes more variance in novice perceivers' judgments is accounted for by non-specifying variables than by a specifying variable (see e.g. Gilden and Proffitt, 1989). Indeed, Jacobs and Michaels (2007) proposed that perceivers in novel situations are likely to use such variables on their way to direct perception. So what was needed was a theory that explains how perceivers come to use specifying information. The theory does not abandon specificity, but invokes it at the level of learning rather than perception. While direct learning is not mainstream ecological theory, it is included here because it illustrates in a simple way, we hope, ecological concepts that have been continual sticking points for psychologists and philosophers: learning without storage, representation, or memory.

Three ideas constitute the core of direct learning. The first is the concept of *information space*, which is said to comprise all the information variables that perceiver-actors might use in some task. Loci in the space differ in how well they constrain perception or action to be appropriate:

some are good; some are not so good. These information spaces are local; they are structured by both global and local constraints. Information space replaces ecological psychology's single, specifying invariant as the informational basis for some perception or action. The second core idea is that at any point in time (i.e. on the shortest timescale) a perceiver uses information identified by some locus in the space; systematic variance in perception (or action) is accounted for by this variable. We sometimes say that a perceiver "occupies" a locus. Third, learning is understood as movement through the space, where the movement is guided by longer-timescale information—*information-for-learning* (to distinguish it from *information-for-perception* or *-action*). Information-for-learning is hypothesized to be specificational; it directs the learner from the currently occupied locus in information space to the most useful locus. Thus, direct learning surrenders veridical perception in the short term in favor of veridical perception in the long term. Again, the overarching theme is that information alters and improves the fit of situations and actions at many timescales.

To gain some intuition about how this longer-timescale information operates, consider how learning might proceed in a dynamic touch paradigm. A perceiver wields an unseen rod behind a curtain and is asked to report how long it is, which is followed by feedback on actual length. Previous research showed that two moments of inertia were relevant to this judgment. Michaels and colleagues (Michaels, Arzamarski, Isenhower, and Jacobs, 2008) created a one-dimensional space of these variables ranging from complete reliance on one moment of inertia to complete reliance on the other, with their products and ratios occupying loci on the line. One area permitted excellent performance; other areas permitted poorer performance. We found that perceivers often started at suboptimal loci and moved toward more useful loci. We derived a candidate information-for-learning variable—the correlation between the error (reported length – actual length) and the mass of the wielded object. Using information at different loci in the space yielded errors that correlate differently with mass, and those correlations, represented as a vector field in the space, pointed to the optimal. The vector field constitutes an existence proof that information useful for directing change in information use is available at a locus (i.e. does not require comparison of neighboring loci). While one might counter that traditional cue combination could achieve the same changes as were observed in Michaels *et al.*'s (2008) participants, analysis of exploratory movements revealed that perceivers learned to "combine" the inertial moments differently by wielding the rods differently. They learned how to explore so as to detect the optimal information for the task.

In addition to direct learning's success in a number of dynamic touch tasks, the approach has been applied to visual perception of kinetic properties, and to pole balancing. Importantly, the regularities on which the specificity of information-for-learning rest are not limited to those captured by natural law, but include circumstantial and social conventions. This more general view of the constraints that permit specificity and how they act on multiple scales should expand the range of applicability of the ecological approach.

Summary and conclusions

Ten do's and don'ts have been outlined. In many ways, they can be distilled down to one: respect the integrity of the system under investigation; it cannot be indiscriminately decomposed into parts. The backdrop is that the so-called parts depend for their nature and function on the other parts. While it may make sense to take a clock apart, describe the parts, and assess their functions and interrelations, the same cannot be said of living and knowing systems. If one nevertheless persists in decomposition, then the task is to re-embodiment the part or parts and re-embed them in a context. These endeavors are not necessary tasks for cognitive science; they are paying for one's

mistakes. Our ten commandments are meant to promote a more unitary view, both of the organism–environment system and of the natural science with which we study it.

References

- Chapman, S. (1968). Catching a baseball. *American Journal of Physics*, 36, 868–70.
- Clark, A. (1997). *Being there*, Cambridge, MA: MIT Press.
- Dennett, D. I. (1978). *Brainstorms: Philosophical essays on mind and psychology*, Montgomery, VT: Bradford Books.
- Gibson, E. J. (1969). *Principles of perceptual learning and development*. New York: Appleton-Century-Crofts.
- Gibson, J. J. (1966). *The senses considered as perceptual systems*. New York: Houghton-Mifflin.
- Gilden, D. L., and Proffitt, D. R. (1989). Understanding collision dynamics. *Journal of Experimental Psychology: Human Perception and Performance*, 15, 372–83.
- Haken, H., Kelso, J. A. S., and Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biological Cybernetics*, 51, 347–56.
- Iberall, A. S., and McCulloch, W. S. (1969). The organizing principle of complex living systems. *Journal of Basic Engineering*, 19, 290–94.
- Iberall, A. S., and Soodak, H. (1987). The physics of complex systems. In F. E. Yates (Ed.), *Self-organizing systems: The emergence of order* (pp. 521–40). New York: Plenum.
- Jacobs, D. M., and Michaels, C. F. (2007). Direct-learning. *Ecological Psychology*, 19, 321–49.
- Kugler, P. N., and Turvey, M. T. (1987). *Information, natural law, and the self-assembly of rhythmic movement*. Hillsdale, NJ: Erlbaum.
- Marr, D. (1982). *Vision*. Cambridge, MA: MIT Press.
- Michaels, C. F., Arzamarski, R., Isenhowe, R., and Jacobs, D. M. (2008). Direct learning in dynamic touch. *Journal of Experimental Psychology: Human Perception and Performance*, 34(4), 944–57.
- Michaels, C. F., and Carello, C. (1981). *Direct perception*. Englewood Cliffs, NJ: Prentice-Hall.
- Runeson, S. (1977). On the possibility of “smart” perceptual mechanisms. *Scandinavian Journal of Psychology*, 18, 172–79.
- Shaw, R., and Kinsella-Shaw, J. (1988). Ecological mechanics: A physical geometry for intentional constraints. *Human Movement Sciences*, 7, 155–200.
- Turvey, M. T. (1977). Preliminaries to a theory of action with reference to vision. In R. E. Shaw and J. Bransford (Eds.), *Perceiving, acting, and knowing* (pp. 211–65). Hillsdale, NJ: Erlbaum.

Further reading

A. Chemero, *Radical embodied cognitive science* (Cambridge, MA: MIT Press, 2009) (an informed, philosophical consideration of the ecological approach to cognitive science); and M. J. Richardson, K. Shockley, B. R. Fajen, M. A. Richardson, and M. T. Turvey, “Ecological psychology: Six principles for an embodied-embedded approach to behavior,” in P. Calvo and T. Gomila (Eds.), *Handbook of cognitive psychology: An embedded approach* (New York: Elsevier, 2008), pp. 161–87 (an extended treatment of the implications of ecological psychology for embedded, embodied cognition).

PART II

Perspectives on embodied cognition

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3

EXTENDED COGNITION

Ken Aizawa

What takes place in the environment clearly influences cognitive processing. Children raised around speakers of English typically learn to understand English, whereas children raised around speakers of German typically learn to understand German. Accountants using calculators will typically know that accounts are balanced more quickly than those who use pencil and paper. Extended cognition goes beyond such pedestrian observations. Rather than causal dependency relations between cognitive processes and environmental processes, extended cognition postulates a constitutive dependence between cognitive processes and processes in brain, body, and environment. Cognitive processes are realized, not just in the brain, but also in the body and world.

This brief chapter will focus on two types of arguments for extended cognition inspired by Clark and Chalmers (1998). First, there has been the thought that cognition extends when processes in the brain, body, and world are suitably similar to processes taking place in the brain. We might describe these as cognitive equivalence arguments for extended cognition. Second, there has been the thought that, when there is the right kind of causal connection between a cognitive process and bodily and environmental processes, cognitive processes come to be realized by processes in the brain, body, and world. We might describe these as coupling arguments for extended cognition. What critics have found problematic are the kinds of similarity relations that have been taken to be applicable or suitable for concluding that there is extended cognition and the conditions that have been offered as providing the right kind of causal connection.

Cognitive equivalence arguments

The best-known cognitive equivalence argument is Andy Clark and David Chalmers' "Inga-Otto" thought experiment.¹ In this experiment, Inga is a normal human being who hears about an exhibit at the Museum of Modern Art. She decides that she wishes to see it, then pauses to recollect where the museum is. When she remembers, she heads out to 53rd Street. Next consider Otto, an individual suffering from the early stages of Alzheimer's disease. In order to cope with the loss of his biological memory, he turns to a notebook wherein he keeps useful information, such as the location of the museum. When he hears about the exhibit, he decides he

wishes to see it, and then flips through his notebook until he finds the address. When he does, he heads out to 53rd Street.

Clark and Chalmers claim that the information stored in their respective brainy and papery resources constitutes memory for both Inga and Otto. They claim that “in relevant respects the cases are entirely analogous: the notebook plays for Otto the same role that memory plays for Inga. The information in the notebook functions just like the information constituting an ordinary non-occurrent belief; it just happens that this information lies beyond the skin” (Clark and Chalmers, 1998, p. 13). Further, “Certainly, insofar as beliefs and desires are characterized by their explanatory roles, Otto’s and Inga’s cases seem to be on a par: the essential causal dynamics of the two cases mirror each other precisely” (ibid.). And, finally, “To provide substantial resistance, an opponent has to show that Otto’s and Inga’s cases differ in some important and relevant respect. But in what deep respect are the cases different?” (Clark and Chalmers, 1998, pp. 14–15).²

Substantial resistance through non-derived content?

Critics have offered a number of proposals to provide the kind of resistance that Clark and Chalmers demand. One contention has been that Inga’s informational resources bear non-derived content, where Otto’s informational resources bear derived content.³ Non-derived content does not depend upon previously existing content, where derived content does. Stereotypically, non-derived content arises from social conventions. So, the meaning of a red traffic light, the meaning of a white flag, and the meaning of written words are paradigmatic instances of non-derived content.

It is sometimes claimed that cognitive states necessarily bear non-derived content, so that the fact that the letters and numerals in Otto’s notebook presumably bear only derived content suffices to show that the letters and numerals are not constituents of any of Otto’s cognitive states. Of course, bearing non-derived content may be important to cognition, even if it is not a strictly necessary property of a cognitive state. Perhaps cognitive states are natural kinds on the model of homeostatic property clusters.⁴ On this analysis, cognitive states lack necessary or essential properties, such as bearing non-derived content, but they nevertheless tend to have a stable set of similarities, among which may be that they bear non-derived content. Thus, bearing derived content makes the inscriptions in Otto’s notebook less like paradigmatic cognitive states. What this shows is that, in principle, there is more than one metatheoretical means by which to recognize the importance of non-derived content to being cognitive.

Dennett (1986), Clark (2005, 2010), Menary (2010), and Fisher (2009) argue that the derived/non-derived distinction is neither important nor relevant to cognitive status. Prior to the debate over extended cognition, Dennett (1986) gave a multifaceted challenge to the hypothesis of non-derived (or “original”) content. He claimed that there is no distinction between derived and non-derived content, that humans lack non-derived content, and that there is no such thing as original intentionality. Furthermore, in opposition to the view that cognitive content is non-derived, he noted that organisms have the minds they do in virtue of evolution by natural selection. This means that there is a kind of derivation of human minds, hence, Dennett believes, a kind of derivation of the content in their minds. Relating this to the debate over extended cognition, we can see that if all content is derived, then the content in Inga’s brain is derived, just as is the content in Otto’s notebook. So, the derived/non-derived distinction is irrelevant.

Clark (2005) has inspired a different line of attack on the need for cognitive states to bear non-derived content. He invites us to imagine the discovery of a Martian whose brain

manipulates bitmapped images of texts, so that the Martian would be manipulating texts in its brain. Clark claims that we would not hesitate to say that the Martian is doing cognitive processing with items bearing only non-derived content, so that we can see that cognitive processing does not necessarily traffic in only non-derived representations.⁵ Clark (2010) brings the Martian example down to earth by proposing that certain human “memory masters” have the ability to recall image-like representations of texts. Were they to use their image-like representations on texts, then they would be performing cognitive operations on derived representations. Menary (2010) pursues this further by offering cases of “thinking in English.” Words of natural language are paradigms of items bearing derived content, so insofar as “thinking in English” is literally thinking in English, we have cases of cognitive processing that involves trafficking in derived content.

Fisher (2009) argues that it is a mistake to propose that cognitive content must be non-derived, since there are numerous plausible cases of derived cognitive content. He suggests that the contents of thoughts, memories, and imaginational states derive from the contents of perceptual states. Given that the condition cannot hold of Inga’s informational resources, it is too much to demand that it hold of Otto’s.⁶

Substantial resistance from cognitive psychology?

A second potential source of substantial resistance to equating Inga and Otto comes from cognitive psychology. Rupert (2004) draws attention to two features of human memory: the phenomenon of negative transfer and the generation effect.⁷ In the first phase of a typical negative transfer experiment, participants are presented pairs of items, such as a male name (*A*) paired with the name of their significant other (*B*), and trained to a criterion to respond with a *B* item when probed by an *A* item. In the second phase of the experiment, participants are told that the relations of all the *A* individuals have changed. Now, John is not married to Mary, but is married to Sue, and so forth. Thus, participants must learn a new set of *A*–*C* associations that replace the prior *A*–*B* associations. In this second phase, the new *A*–*C* associations are more difficult to learn than the initial *A*–*B* associations. This is the negative transfer effect. *Ex hypothesi* Inga will perform as a typical participant in one of these experiments. By contrast, Otto using his notebook will probably not. In the first phase, Otto will write down all the *A*–*B* pairings on a single page. This will, presumably, enable Otto to reach criterion on the first pass, performance that is quite different from Inga’s. In the second phase, Otto will presumably write all the *A*–*C* pairings on a new page. This will enable Otto to reach criterion again on the first pass, thereby differing dramatically from Inga’s performance. Finally, we see that, with Otto, there is no negative transfer. Learning the *A*–*B* list does not inhibit learning of the *A*–*C* list.⁸

In a typical generation effect experiment, there are two groups of participants. In the first group, participants are given a list of *A*–*B* pairs to memorize; in the second group, participants generate a list of *A*–*B* pairs by reading a sentence, such as “The cow chased the ball.” In both groups, participants develop a list of *A*–*B* pairs, such as “cow-ball,” but participants who generate the pairs by reading sentences have better memory recall. This again applies straightforwardly to the Inga–Otto case. If we suppose that Inga is a normal human being, then *ex hypothesi* she will perform better when she is in the group that generates its *A*–*B* list by sentence reading than when she is in the group that is given the *A*–*B* list. By contrast, whichever group Otto is in, he will write down the items in the *A*–*B* list, then recall as necessary later. He will perform just as well in the generation condition as in the non-generation condition.

The generation effect and negative transfer effect seem to show that Clark and Chalmers are mistaken in their contention that Inga and Otto are in all important and relevant respects the

same. Notice, as well, that this line of response can go beyond merely showing that Clark and Chalmers overstated their case for the similarity between Inga and Otto. We can draw attention to many other features of memory to argue, as does Rupert (2004), that external “memory” processing differs so dramatically from internal memory processing that these should not be treated as instances of a single natural kind. In advancing this argument, we do not have to say that any one feature, such as the negative transfer effect or the generation effect, is a necessary feature of memory. As noted above, we may, instead, propose that the particular features of memory that cognitive psychologists have so far discovered are elements in a much larger, perhaps poorly understood, homeostatic property cluster that constitutes human long-term memory as a natural kind. Thus, the more Inga and Otto differ in the properties that scientists have come to associate with long-term memory, the stronger is the case for saying that Inga and Otto do not have the same kind of “memory.”

As emphasized above, Clark and Chalmers apparently believed that Inga and Otto are in *all* important and relevant respects the same.⁹ Nevertheless, advocates of extended cognition need not take such a strong position. They can instead propose that Inga and Otto are in *some* important and relevant respects the same. If that were the case, there could be some sort of cognition that extends. This, in fact, seems to have become the favored defense of extended cognition.

So, what kind of important and relevant cognition is extended? There is no single answer. One proposal from Clark (2009) is that something like *folk psychology* is extended. Folk psychology consists of a largely implicit theory people have about the way humans perform in various situations. Perhaps, therefore, we could say that the hypothesis of extended *folk* cognition is true, important, and relevant, while conceding that the hypothesis of extended *scientific* cognition is false. Rowlands (2009) thinks that some form of *liberal functionalism* fits the bill.

It is generally accepted that the arguments for EM [extended mind] presuppose functionalism. More than that, they presuppose a peculiarly *liberal* form of functionalism. Indeed, there is a way of understanding functionalism according to which EM emerges as a straightforward, almost *trivial*, consequence. In its more liberal forms, functionalism is based on a *principled* indifference to the details of the physical structures that realize mental processes. What is crucial to a mental state or process is its functional role, not its physical realization. For the liberal functionalist: if it walks like a duck, and talks like a duck, then it is a duck. *How* it manages to walk and talk like a duck is not directly relevant. To this, EM simply adds: neither does it matter where it walks and talks like a duck.

(Rowlands, 2009, pp. 56–57)

Following Rowlands, then, we may say that the hypothesis of *liberal functionalist* cognition is true, important, and relevant, while conceding that the hypothesis of *scientific* cognition is false. Of course, whatever version of this approach we adopt, be it Clark’s, or Rowlands’, or some other, we do want some explanation of the importance of these forms of cognition and their extension and what relevance they have to scientific and philosophical projects.

Coupling arguments

Far more prevalent than cognitive equivalence arguments are a group of so-called “coupling arguments.” So, to return to Clark and Chalmers’ discussion, they argue that:

It is not just the presence of advanced external computing resources which raises the issue, but rather the general tendency of human reasoners to lean heavily on environmental supports. Thus consider the use of pen and paper to perform long multiplication ... , the use of physical re-arrangements of letter tiles to prompt word recall in Scrabble ... , the use of instruments such as the nautical slide rule ... , and the general paraphernalia of language, books, diagrams, and culture.

(Clark and Chalmers, 1998, p. 8)

Then, somewhat later, they write

In these cases, the human organism is linked with an external entity in a two-way interaction, creating a *coupled system* that can be seen as a cognitive system in its own right. All the components in the system play an active causal role, and they jointly govern behavior in the same sort of way that cognition usually does. If we remove the external component the system's behavioral competence will drop, just as it would if we removed part of its brain. Our thesis is that this sort of coupled process counts equally well as a cognitive process, whether or not it is wholly in the head.

(Ibid., pp. 8–9)

These passages invite the following interpretation: when a process X has a causal influence on a cognitive process Y , then we may infer that the entire X - Y process is a cognitive process. This interpretation is reinforced if we bear in mind the introduction to Clark and Chalmers (1998), where they write, “We advocate a very different sort of externalism: an *active externalism*, based on the active role of the environment in driving cognitive processes” (ibid., p. 7).

While there are texts that suggest this line of argumentation, it is now common ground among advocates and critics of extended cognition that this simple argument is fallacious.¹⁰ Just because a process X causally influences a cognitive process Y does not seem to be a sound basis upon which to infer that the whole X - Y process is cognitive. Consider this kind of reasoning in another context. Let X be the process of evaporative cooling found in a typical home air conditioning system. In a normal working system, this process is causally coupled to a process Y of deformation in the shape of a bimetallic strip in a thermostat in one room of the house. This causal linkage between X and Y does not make the entire X - Y process a process of shape deformation. For that matter, it does not make the whole X - Y process a matter of evaporative cooling.

While many advocates of extended cognition admit that there is this “coupling-constitution fallacy,” they also sometimes suggest that this is not a mistake anyone has committed and leave the matter at that. Alternatively, they take the argument to be that cognition extends when there is the *right kind* of causal connection between brainy cognitive processes and bodily and environmental processes. The simplistic coupling-constitution fallacy sketched above does not speak to this more subtle claim.

These replies, however, underestimate the challenge of moving from causal claims to constitutive claims. Rather than viewing the simple coupling-constitution fallacy as the end of a story, we should take it to be a starting point. It should lead us to ask how to refine the mistaken, simplistic account into a correct, sophisticated account. There are, however, two challenges lurking here. First of all, if we propose that additional conditions, C_1, \dots, C_n , are needed in order for coupling relations to suffice to establish constitutive relations, then we must bear the burden of determining and theoretically validating those additional conditions C_1, \dots, C_n . Second, once we establish a valid set of conditions, if we subsequently wish to show that we

have an actual instance of extended cognition, as when using pen and paper to perform a long multiplication, then we will have to show that the putative actual instance satisfies C_1, \dots, C_n . Moreover, the challenges interact. The more restrictive the set of theoretically valid conditions we develop, the greater the argumentative burden that will be needed in order to establish that they apply in any particular putative instance. Moreover, the more restrictive the set of theoretically valid conditions we develop, the fewer real-world instances we are likely to find to satisfy them.

To get a sense of this, let us consider a relatively trivial strengthening of the causal conditions that might be thought to suffice for a constitutive relation. Perhaps we should say that when a process X has a *reliable* causal influence on a cognitive process Y , then we may legitimately infer that the entire X - Y process is cognitive. Clark and Chalmers seem to have such an idea in mind when they write,

for coupled systems to be relevant to the core of cognition, *reliable* coupling is required. It happens that most reliable coupling takes place within the brain, but there can easily be reliable coupling with the environment as well. If the resources of my calculator or my Filofax are always there when I need them, then they are coupled with me as reliably as we need. ... If the relevant capacities are generally there when they are required, this is coupling enough.

(Clark and Chalmers, 1998, p. 8)

Now return to the two challenges. In the first place, is a reliable causal connection really enough to warrant the conclusion that there is an extended cognitive process? Revisit the example of an air conditioning system. Let the process X of evaporative cooling be *reliably* causally coupled to the process Y of deformation in the shape of a bimetallic strip. This does not seem to make a difference. This reliable causal linkage between X and Y does not make the entire X - Y process into a process of shape deformation. In this instance, reliable causal connection does not seem to determine the character of a process. So, the addition of the reliability condition does not seem to suffice to circumvent the coupling-constitution fallacy.¹¹ In the second place, reflect on the implications of the reliability condition. With this condition, not all uses of pen and paper for long multiplication will be instances of extended cognition. Cases in which an agent always has pen and paper at hand to do long multiplication will count as instances of extended cognition, where cases in which those implements are only occasionally available will not. This means that there are likely to be fewer instances of extended cognition than Clark and Chalmers may have led us to expect.

For a second illustration of the interaction between the two challenges, we could consider a set of more stringent conditions proposed by Clark and Chalmers:

First, the notebook is a constant in Otto's life—in cases where the information in the notebook would be relevant, he will rarely take action without consulting it. Second, the information in the notebook is directly available without difficulty. Third, upon retrieving information from the notebook he automatically endorses it. Fourth, the information in the notebook has been consciously endorsed at some point in the past, and indeed is there as a consequence of this endorsement.

(Clark and Chalmers, 1998, p. 11)

One may think that these conditions adequately meet the first challenge by yielding correct results for cases such as Otto's use of his notebook, but they also appear to rule out instances of

bona fide memory. They appear to disallow cases of “alienation” from one’s own cognitive resources. So, suppose that, for whatever reason, Dotto comes to the conclusion that he should not trust his memory to correctly recall people’s names. Although he always does correctly recall the name of a person he sees, he does not trust his memory. Rather than take a chance on misidentifying someone, he either avoids the person or asks someone nearby to confirm his recollection. In this scenario, Dotto violates the first and third of Clark and Chalmers’ conditions, suggesting that Dotto’s memory is not really involved in cognitive processing.¹²

These sorts of examples, of course, do not prove that it is impossible to meet the two challenges. They do not show that it is impossible to find actual cases in which cognition extends when there is the *right kind* of causal connection between internal cognitive processes and bodily and environmental processes. Instead, they evidently establish the coupling-constitution fallacy as a provocation to further investigation.¹³

Conclusions

This chapter has focused on two prominent types of arguments for extended cognition, cognitive equivalence arguments and coupling arguments. These are perhaps best thought of as families of arguments. The members of the cognitive equivalence family differ among themselves regarding the standard of cognitive equivalence – for example, equivalence in all important and relevant respects, or equivalence in one or another respect. The members of the coupling family differ among themselves regarding what conditions, over and above a simple causal connection, warrant the conclusion that some process external to the brain constitutes a cognitive process. Insofar as we are concerned with the conditions under which there might be extended cognition, these appear to be the core approaches.¹⁴

Notes

- 1 The only other well-known cognitive equivalence argument is Clark and Chalmers’ thought experiment with the video game Tetris. This argument was inspired by Kirsh and Maglio (1995).
- 2 In a similar bold spirit, Mark Rowlands claims “there is no sound theoretical reason for setting up a dichotomy between internal memory processes and external aids to those processes” (Rowlands, 1999, p. 121).
- 3 See, for example, Adams and Aizawa, 2001, 2008; and Fodor, 2009.
- 4 See, for example, Boyd, 1999a, 1999b.
- 5 For further discussion, see Clark, 2010.
- 6 For further discussion, see Adams and Aizawa, 2008; and Aizawa, 2010.
- 7 See Adams and Aizawa, 2008 for other examples of this sort.
- 8 Of course, we might try to modify the original Otto example in such a way as to display the negative transfer effect. Perhaps Otto does not write the *A-C* pairings on a new sheet of paper, but imperfectly erases the *B* entries and writes the *C* entries where the old *B* entries were. This way of entering the pairings may make it harder for Otto to write them correctly on the first try. And maybe this will make it harder for Otto to read the *A-C* pairings, which might explain why it takes him longer to get the *A-C* pairings right.
- 9 Also recall Rowlands’ claim that “there is no sound theoretical reason for setting up a dichotomy between internal memory processes and external aids to those processes” (1999, p. 121).
- 10 See, for example, Clark, 2009; Fisher, 2009; and Wilson, 2010.
- 11 Notice that the reciprocal causal interaction between *X* and *Y* does not appear to make a difference. And, would it make a difference if the interaction between *X* and *Y* were non-linear?
- 12 For other examples in this vein, see Adams and Aizawa, 2008, ch. 7.
- 13 Other sets of condition on coupling will be found in van Gelder (1995) and Haugeland (1998). More recently, Chemero (2009) and Froese, Gershenson, and Rosenblueth (2013) have proposed that cognition extends when there is a non-linear coupling between brain processes and environmental

processes, where Roberts (2012) has proposed that true cognitive extension occurs only when the subject takes responsibility for the contribution made by a non-neural resource.

14 For an alternative to causal coupling arguments, see Gillett, 2013, and the commentary in Aizawa, 2013.

References

- Adams, F., and Aizawa, K. (2001). The bounds of cognition. *Philosophical Psychology*, 14(1), 43–64.
- (2008). *The bounds of cognition*. Malden, MA: Blackwell Publishers.
- Aizawa, K. (2010). The boundaries still stand: A reply to Fisher. *Journal of Mind and Behavior*, 31(1–2), 37–47.
- (2013). Introduction to “The material bases of cognition.” *Minds and Machines*, 23(3), 277–86.
- Boyd, R. (1999a). Homeostasis, species, and higher taxa. In R. Wilson (Ed.), *Species: New interdisciplinary essays* (pp. 141–85). Cambridge, MA: MIT Press.
- (1999b). Kinds, complexity and multiple realization: Comments on Millikan’s “Historical kinds and the special sciences.” *Philosophical Studies*, 95(1), 67–98.
- Chemero, A. (2009). *Radical embodied cognitive science*. Cambridge, MA: MIT Press.
- Clark, A. (2005). Intrinsic content, active memory and the extended mind. *Analysis*, 65(1), 1–11.
- (2009). *Supersizing the mind: Embodiment, action and cognitive extension*. New York: Oxford University Press.
- (2010). Memento’s revenge: The extended mind, extended. In R. Menary (Ed.), *The extended mind* (pp. 43–66). Cambridge, MA: MIT Press.
- Clark, A., and Chalmers, D. (1998). The extended mind. *Analysis*, 58(1), 7–19.
- Dennett, D. C. (1986). The myth of original intentionality. In K. A. Mohyeldin Said, W. H. Newton-Smith, R. Viale, and K. V. Wilkes. (Eds.), *Modeling the mind* (pp. 43–62). Oxford: Oxford University Press.
- Fisher, J. (2009). Critical notice of the book *The bounds of cognition*, by F. Adams and K. Aizawa. *Journal of Mind and Brain*, 29(4), 345–57.
- Fodor, J. (2009). Where is my mind? *London Review of Books*, 31(2), 13–15.
- Froese, T., Gershenson, C., and Rosenblueth, D. A. (2013). The dynamically extended mind: A minimal modeling case study. Paper presented at the IEEE Congress on Evolutionary Computation, CEC 2013, Evolutionary Robotics track, Cancun, Mexico, June.
- Gillett, C. (2013). Constitution, and multiple constitution, in the sciences: Using the neuron to construct a starting framework. *Minds and Machines*, 23(3), 309–37.
- Haugeland, J. (1998). Mind embodied and embedded. In J. Haugeland (Ed.), *Having thought: Essays in the metaphysics of mind* (pp. 207–37). Cambridge: Harvard University Press.
- Kirsh, D., and Maglio, P. (1995). Some epistemic benefits of action: Tetris, a case study. *Proceedings of the Fourteenth Annual Conference of the Cognitive Science Society*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Menary, R. (2010). The holy grail of cognitivism: A response to Adams and Aizawa. *Phenomenology and the Cognitive Sciences*, 9(4), 605–18.
- Roberts, T. (2012). You do the maths: Rules, extension, and cognitive responsibility. *Philosophical Explorations*, 15(2), 133–45.
- Rowlands, M. (1999). *The body in mind: Understanding cognitive processes*, New York: Cambridge University Press.
- (2009). Enactivism and the extended mind. *Topoi*, 28(1), 53–62.
- Rupert, R. (2004). Challenges to the hypothesis of extended cognition. *Journal of Philosophy*, 101(8), 389–428.
- van Gelder, T. (1995). What might cognition be, if not computation? *Journal of Philosophy*, 92, 345–381.
- Wilson, R. (2010). Extended vision. In N. Gangopadhyay, M. Madary, and F. Spicer (Eds.), *Perception, action and consciousness: Sensorimotor dynamics and two visual systems* (pp. 277–90). Oxford: Oxford University Press.

4

COMPLEX DYNAMICAL SYSTEMS AND EMBODIMENT

Michael J. Richardson and Anthony Chemero

Although dynamical systems have been used by cognitive scientists for more than a decade already (e.g. Kugler, Kelso, and Turvey, 1980), dynamical systems first gained widespread attention in the mid-1990s (e.g. Kelso, 1995; Port and van Gelder, 1995; Thelen and Smith, 1994). Dynamical systems theory was then, and continues to be, a crucial tool for embodied cognitive science. The word *dynamical* simply means “changing over time” and thus a *dynamical system* is simply a system whose behavior evolves or changes over time. The scientific study of dynamical systems is concerned with understanding, modeling, and predicting the ways in which the behavior of a system changes over time. In the last few decades, thanks to increasing computational power, researchers have begun to investigate and understand the dynamic behavior of complex biological, cognitive, and social systems, using the concepts and tools of non-linear dynamical systems. In the next section, we will describe the key concepts of modern dynamical systems theory (complexity, self-organization, soft assembly, interaction dominance, and non-linearity). In the second section, we briefly discuss some dynamical analysis techniques used in the cognitive sciences. In the third, we give some examples of the application of complex dynamical systems theory and analysis in cognitive science. In the last, we sketch some consequences of the widespread applicability of dynamical approaches to understanding neural, cognitive, and social systems.

Complex dynamical systems

Complex dynamical systems exhibit three key characteristics (Gallagher and Appenzeller, 1999). First, they consist of a number of interacting components or agents. These components can be homogeneous or heterogeneous. A collection of cortical areas or simple artificial agents can comprise a homogeneous, complex dynamical system; a brain in a body in an environment can comprise a heterogeneous, complex dynamical system. A second property is that these systems exhibit *emergent* behavior in that their collective behavior exhibits a coherent pattern that could not be predicted from the behavior of the components separately. Third, and most importantly, this emergent behavior is *self-organized* in that it does not result from a controlling component agent. These three characteristics can be seen clearly in phenomena such as bird flocking. Starlings, for example, gather in flocks of hundreds to thousands known as “murmurations.” Starling murmurations exhibit striking, globally unified behavior, in which large numbers of starlings move as a single, dark blob that changes shape as it moves across the sky. Murmurations are a

coordination phenomenon in which interactions between individuals produce collective, large-scale patterns. Starling murmurations, and bird flocks more generally, exhibit all the key features of complex dynamical systems and have been modeled as such (Cavagna *et al.*, 2010).

Self-organization

The term “self-organization” is used to refer to behavioral patterns that emerge from the interactions that bind the components of a system into a collective system, without a centralized controller. A murmuration’s behavior is emergent and self-organized: murmurations form when sufficient numbers of starlings gather, without a head starling leading the way. In fact, in order to model the velocity of individual birds in a murmuration, Cavagna *et al.* (2010) start with the velocity of the murmuration as a whole, and work inward from there to model the velocities of individual birds. Starling flocking highlights how coordinated social behavior can result spontaneously from the interactions of agents. Coordinated, collective behavior among herds of mammals and schools of fish is self-organized in the same way, as is the nest-building behavior of ants, bees, and termites. In each of these cases, no individual animal or subset of the whole controls the behavior of the group (Camazine *et al.*, 2001).

Soft-assembly

Murmurations are temporary coalitions of starlings that are put together in a fluid and flexible manner. It doesn’t matter which particular bird ends up in which position in the flock, and each bird will take up many different positions as the flock moves and takes shape. The behavior of the birds that are the components in the flock is context dependent. Dynamical systems that exhibit this kind of emergent, context-dependent behavior are often referred to as *softly assembled* systems, in that the behavioral system reflects a temporary coalition of coordinated entities, components, or factors. The term *synergy* is sometimes used to refer to softly assembled systems—a functional grouping of structural elements that are temporarily constrained to act as a single coherent unit (Kelso, 2009). In contrast, most non-biological systems or machines are hard-molded systems. A laptop computer, for example, is a hard-molded system, in that it is composed of a series of components, each of which plays a specific, predetermined role in the laptop’s behavior. Coordinated behavior in social animals, including humans, is often softly assembled.

Interaction-dominant dynamics

Softly assembled systems exhibit interaction-dominant dynamics, as opposed to component-dominant dynamics. For component-dominant dynamical systems, system behavior is the product of a rigidly delineated architecture of system modules, component elements or agents, each with predetermined functions. For softly assembled, interaction-dominant dynamical systems, system behavior is the result of *interactions between* system components, agents, and situational factors, with these intercomponent or interagent interactions altering the dynamics of the component elements, situational factors and agents themselves (Anderson, Richardson, and Chemero, 2012; Van Orden, Kloos and Wallot, 2011). As noted above, to model the behavior of individual starlings in a murmuration, Cavagna *et al.* (2010) began with the behavior of the flock as a whole. Within the murmuration, the behavior of any bird is primarily determined by the behavior of the whole murmuration, even though the murmuration is nothing other than the collection of individual birds. If one were to examine the relationship between any two levels of an interaction-dominant dynamical system, one would observe that elements or agents at the

lower level of the system modulate the macroscopic order of the higher level, and at the same time are structured by the macroscopic order of the system. For interaction-dominant systems, it is difficult, and often impossible, to assign precise causal roles to particular components. It is also difficult, and often impossible, to predict the behavior of components within interaction-dominant systems from their behavior in isolation.

Non-linearity

A non-linear system is one in which the system's output is not directly proportional to the input, as opposed to a linear system in which the output can be simply represented as a weighted sum of input components. Complex dynamical systems are non-linear in this sense, so their behavior is never merely the sum of the behavior of the components (Van Orden, Holden, and Turvey, 2003). Non-linearity cuts two ways. On one hand, the non-linearity of complex dynamical systems makes them much more difficult to understand. In fact, non-linear systems are non-decomposable, in that you cannot isolate components of the system and predict their behavior. On the other hand, it is only because complex dynamical systems are non-linear that they can exhibit complex behavior.

Dynamical analysis

Central to identifying the causal structures or processes that underlie and shape the physical and cognitive behavior of complex biological agents is time-series analysis. Substantial advances in the types of *non-linear* analysis techniques that have occurred in recent years, combined with the increasing availability of these techniques (i.e. via open source software packages and code sharing), has further compounded their importance. In fact, it is becoming increasingly clear that non-linear time-series analysis is essential for understanding how the ordered regularity of human behavior and cognition can emerge and be maintained. The advantage of these methods over the traditional statistical techniques commonly employed in cognitive psychology is that they can handle the time dependence of behavior and are not restricted to making linear assumptions about behavioral organization. Indeed, contemporary methods of non-linear dynamics embrace the complexity of self-organized behavior and, accordingly, can provide deep insights about the behavior of real-world time-evolving processes. Here we discuss two methods of non-linear time-series analysis that have had a transformative impact on our ability to classify and understand a wide range of embodied cognition, namely recurrence analysis and fractal analysis.

Recurrence analysis

Recurrence analysis is a phase-space method that allows one to determine the dynamical structure of a recorded time series, no matter how complex the time series is, nor the number of state dimensions needed to capture the time series within its corresponding state space. The beauty of recurrence analysis, in comparison to other time-series methods, is that it does not require one to make any assumptions about the structure of the time series being investigated: it can be stationary, non-stationary periodic, stochastic, discrete, or categorical.

Essentially, recurrence analysis identifies the dynamics of a system by discerning (a) whether the states of system behavior recur over time and, if states do recur, (b) the deterministic regularity of the patterning of recurrences. Conceptually, performing recurrence analysis on behavioral data is relatively easy to understand; one simply plots whether recorded points, states, or events in a time series are revisited or reoccur over time on a two-dimensional plot, called a recurrence

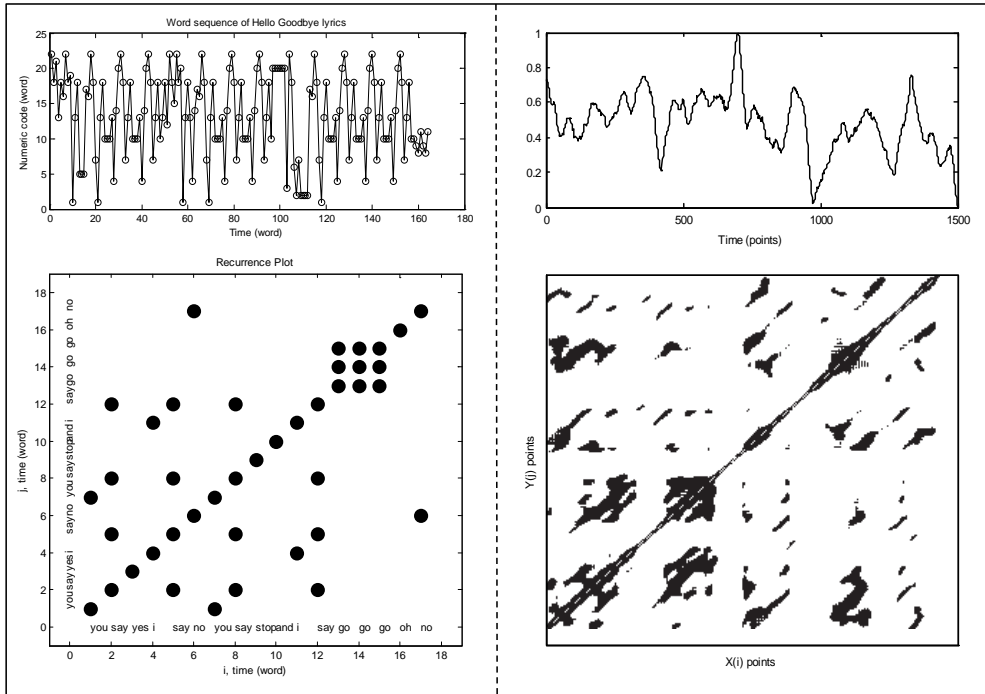


Figure 4.1 Categorical and continuous recurrence analysis. (Left top) The full time series of words extracted from the lyrics of “Hello, Goodbye” by the Beatles. The y-axis represents the numeric identifier to which a word is assigned, and the x-axis represents word-by-word unfolding of this “lexical” time series. (Left bottom) A recurrence plot of the first 20 words in the lyrics. Each point on the plot represents a relative point (i,j) in the lyrics at which a word is recurring (see e.g. Dale and Spivey, 2005, 2006). (Right top) The anterior-posterior postural sway movements of single individual standing and listening to another person speak for 30 seconds. (Right bottom) A recurrence plot of the first 10 seconds of postural data. Despite the non-periodic nature of the postural movement, the recurrence plot reveals deterministic structure. (Adapted from Richardson *et al.*, 2014.)

plot. This plot provides a visualization of the patterns of revisitations in a system’s behavioral state space and can be quantified in various ways in order to identify the structure of the dynamics that exist (see Marwan, 2008 for details). The plots in Figure 4.1 are examples of what recurrence plots look like for a categorical (left plot) and continuous (right plot) behavioral time series.

Recurrence analysis can also be extended to uncover the dynamic similarity and coordinated structure that exists between two different behavioral time series. This latter form of recurrence analysis is termed *cross-recurrence analysis* and is performed in much the same way as standard (auto-)recurrence analysis. The key difference is that recurrent points in cross-recurrence correspond to states or events in two time series that are recurrent with each other. Cross-recurrence analysis can therefore be employed to quantify the co-occurring dynamics of two behavioral time series.

Fractal analysis

Researchers in cognitive and behavioral psychology commonly collapse repeated measurements into summary variables, such as the mean and standard deviation, under the assumption that the

measured data contain uncorrelated variance that is normally distributed. Real-time behavior and cognition, however, are rarely static and thus summary statistics often reveal little about how a system evolves over time. Indeed, time-series recordings of human performance and cognition typically contain various levels of correlated variance or non-random fluctuations that are not normally distributed (Stephen and Mirman, 2010) and, moreover, are structured in a *fractal* or *self-similar* manner (Gilden, 2001, 2009; Van Orden *et al.*, 2003; Van Orden *et al.*, 2011). Indexing the correlated and self-similar variance within a behavioral time series requires the use of fractal methods of analysis, sometimes called *fractal statistics*.

A fractal or self-similar pattern is simply a pattern that is composed of nested copies of itself and looks similar at different scales of observation. A fractal time series is therefore a time series that contains nested patterns of variability (Figure 4.2). That is, the patterns of fluctuation over time look similar at different scales of magnification. The time series displayed in Figure 4.2 is a good example, with the self-similarity of its temporal fluctuations revealed by zooming in on smaller and smaller sections. At each level of magnification the temporal pattern looks similar (Holden, 2005).

A fractal time series is characterized by an inverse proportional relationship between the power (P) and frequency (f) of observed variation. That is, for a fractal time series there exists a proportional relationship between the size of a change and how frequently changes of that size occur, with this relationship remaining stable across changes in scale. It is in this sense that the pattern of variability in a repeatedly measured behavior is self-similar; large-scale changes occur

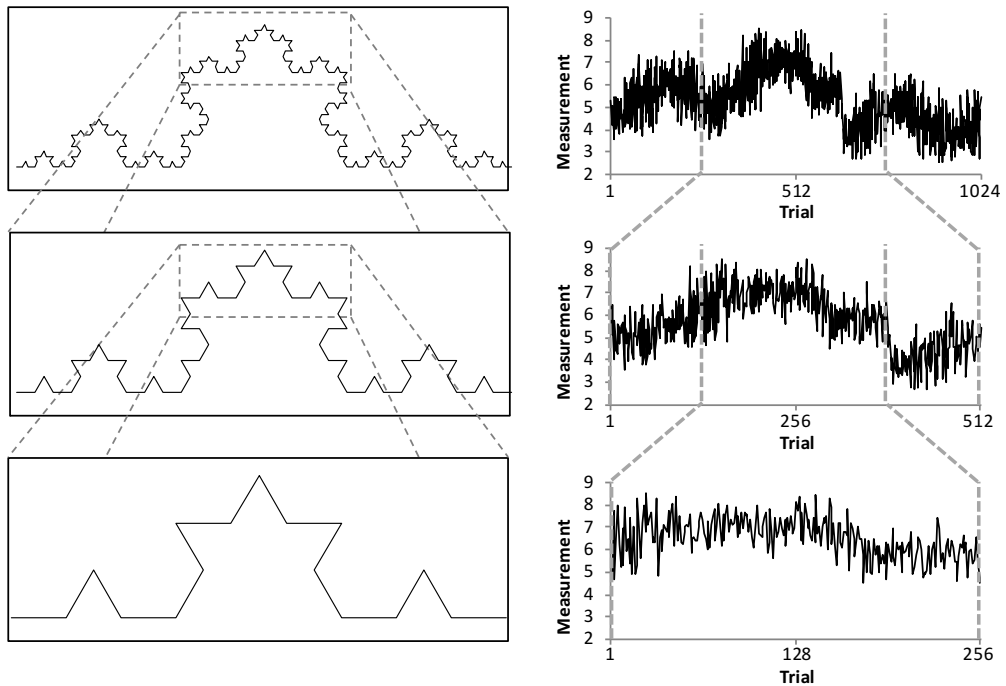


Figure 4.2 Example geometric and temporal fractal patterns (i.e. contain self-similar structure at different magnitudes of observation). (Left) Koch Snowflake at three levels of magnification. (Right) Fractal time series at three levels of magnification. (Adapted from Holden, 2005.)

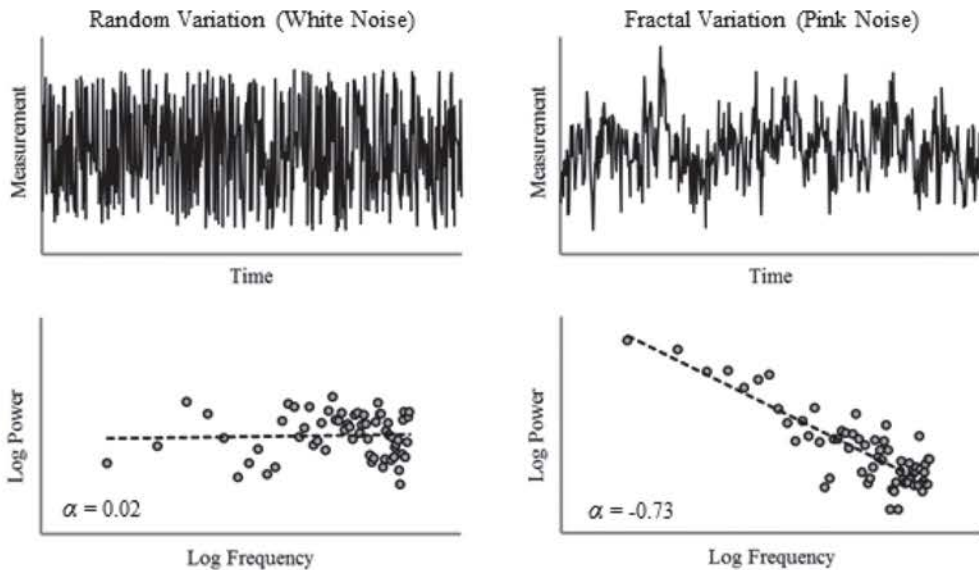


Figure 4.3 Examples of time series composed of random variation (left) and fractal variation (right) and the associated log-log spectral plots.

with the same *relative* frequency as small-scale changes. The degree to which a data set approximates this ideal relationship between power and frequency, $P = 1/f^\alpha$, is summarized in the scaling exponent, α . If one plots the power of the different spectral frequencies that make up a time series on double-logarithmic axes, α is equivalent to the slope of the line that best fits the data (Figure 4.3). That is, α captures the relationship between size and frequency of fluctuations in the time series of behavior. Random fluctuations (i.e. white noise) produce a flat line in a log-log spectral plot with a slope close to 0, which indicates that changes of all different sizes occur with approximately the same frequency. Alternatively, fractal fluctuations, often referred to as pink or $1/f$ noise, produce a line in a log-log spectral plot that has a slope closer to -1 , which indicates the scale-invariant scaling relationship characteristic of fractal patterns.

The import of determining whether a behavioral time series contains fractal or $1/f$ variability is highlighted by a growing body of research demonstrating that the most human behaviors exhibit fractal structure. For example, numerous studies have demonstrated how the fluctuations in time series of ongoing stimulus-response activity, time estimation, cognitive performance, postural control, and eye movements exhibited fractal structure (see Delignières *et al.*, 2006; Gilden, 2009; Holden, 2005). Even the flow of social interaction and behavior has a fractal structure (e.g. Delignières, Fortes, and Ninot, 2004; Newton, 1994). Of particular relevance for the current discussion, however, is that this research has also demonstrated that the degree to which fluctuations within a behavioral time series are fractal (i.e. pink) or not (i.e. white), can provide evidence about whether a behavior is non-linear and the result of interaction-dominant dynamics (Van Orden *et al.*, 2003).

Complex, dynamical cognitive systems

The above analysis techniques have been applied widely at all spatial scales relevant to cognitive science, from brain areas, to embodied behavior, to agent-environment systems, and to social interaction. Although recurrence analysis is still relatively new, there is now substantial evidence

to suggest that it is potentially one of the most generally applicable methods for assessing the dynamics of biological and human behavior (e.g. Marwan and Meinke, 2002; Zbilut, Thomasson, and Webber, 2002). This is due to the fact that recurrence analysis provides researchers with a way of determining whether the nested fluctuations and complex time-evolving patterns within almost any type of behavioral time series are deterministic and interrelated or stochastic and disconnected (i.e. the degree a behavioral structure is the result of interaction-dominant dynamics). For instance, auto- and cross-recurrence analysis has already been employed to uncover the non-obvious changes that goal constraints produce on the synergistic dynamics of postural movements (Riley, Balasubramaniam, and Turvey, 1999), the noise structure of limb movements (e.g. Pellecchia, Shockley, and Turvey, 2005; Richardson, Schmidt, and Kay, 2007) the intermitted perceptual-motor synchrony that occurs between people interacting (Richardson and Dale, 2005; Richardson, Marsh, and Schmidt, 2005; Richardson, Marsh, Isenhowe, Goodman, and Schmidt, 2007; Shockley, Santana, and Fowler, 2003; Shockley, Baker, Richardson, and Fowler, 2007), the deterministic structure inherent in eye movements and stimulus-response reaction-time data (e.g. Cherubini, Nüssli, and Dillenbourg, 2010; Pannasch, Helmert, Müller, and Velichkovsky, 2012), even semantic similarity during conversation (Angus, Smith, and Wiles, 2011) and the vocal dynamics of children during development (Warlaumont *et al.*, 2010). In each case, recurrence analysis was able to reveal whether the observed dynamics were the result of nested physical, neural, and informational couplings that bound cognition and action to each other and to the relevant objects (individuals) and events within the task environment.

As noted above, the presence of $1/f$ scaling and complex patterns of recurrent structure in a cognitive and behavioral phenomenon is evidence that the softly assembled system is interaction dominant. Complex patterns of recurrent behavior and $1/f$ scaling has been observed in the brain, and in a wide variety of cognitive and behavioral tasks, from tapping, to key pressing, to word naming, and many others (Van Orden *et al.*, 2011). This indicates that softly assembled coalitions of components encompassing portions of the participants' brain and body were responsible for the performance of the experimental task. That the portions of the cognitive system that engage in tasks such as these are not fully encapsulated in the brain is perhaps not surprising, since each has a strong motor component. But we also see time-evolving recurrent structures and $1/f$ scaling in "purely cognitive" phenomena. In one example, Stephen, Dixon, and Isenhowe (2009) have shown that problem-solving inference is accomplished by an interaction-dominant system. Using fractal statistics and recurrence analysis, they found that learning a new strategy for solving a problem coincides with changes in the complexity and amount of recurrent activity in an individual's eye movements. This indicates that even leaps of insight do not occur in the brain alone—the eye movements are part of the interaction-dominant system that realizes the cognitive act. Findings such as this impact not only the extent of the biological resources required for cognitive faculties, but also the separation of cognitive faculties from one another. Finding that moving eyes are components of the interaction-dominant system that has the problem-solving insight makes it more difficult to separate cognition from motor control.

There is reason to think that this expansion of the cognitive system does not stop at the boundaries of the biological body. For example, Dotov, Nie, and Chemero (2010) describe experiments designed to induce and then temporarily disrupt an extended cognitive system. Participants in these experiments play a simple video game, controlling an object on a monitor using a mouse. At some point during the 1-minute trial, the connection between the mouse and the object it controls is disrupted temporarily before returning to normal. Dotov *et al.* found $1/f$ scaling at the hand-mouse interface while the mouse was operating normally, but not

during the disruption. As discussed above, this indicates that, during normal operation, the computer mouse is part of the smoothly functioning interaction-dominant system engaged in the task; during the mouse perturbation, however, the $1/f$ scaling at the hand-mouse interface disappears temporarily, indicating that the mouse is no longer part of the extended interaction-dominant system. These experiments were designed to detect, and did in fact detect, the presence of an extended cognitive system, an interaction-dominant system that included both biological and non-biological parts. The fact that such a mundane experimental set-up (using a computer mouse to control an object on a monitor) generated an extended cognitive system suggests that extended cognitive systems are quite common. These, of course, are not the only examples of interaction dominance in cognition (for a review, see Van Orden *et al.*, 2011).

The phenomena of $1/f$ scaling and recurrent dynamics are ubiquitous in the brain as well. Heterogeneous coupling and multiscale dynamics are widespread features of the brain. Brain connectivity is organized on a hierarchy of scales ranging from local circuits of neurons to functional topological networks. At each scale the relevant neural dynamics are determined not just by processes at that scale, but by processes at other smaller and larger scales as well. Such multilevel clustered architectures promote varied and stable dynamic patterns via criticality and other dynamical and topological features. There is therefore also growing evidence that neural circuits are interaction dominant. Several recent studies have found evidence of $1/f$ scaling in human neural activity (e.g. Freeman, Rogers, Holmes, and Silbergeld, 2000; Bullmore *et al.*, 2001; Freeman, 2009). Research on the dynamics of brain activity using recurrence analysis has also produced evidence that the dynamic behavior of the brain is characteristic of an interaction-dominant system. For example, Acharya and colleagues have employed recurrence analysis to uncover the non-linear and interaction-dominant dynamics of EEG singles during various sleep cycles and for individuals with epilepsy (e.g. Acharya, Faust, Kannathal, Chua, and Laxminarayan, 2005).

Finally, the dynamics of many social behaviors are interaction dominant and characterized by complex recurrent patterns and $1/f$ scaling. For instance, Shockley *et al.* (2003) employed cross-recurrence analysis to examine the postural dynamics of two co-present participants completing a conversational task together. The experiment included two key manipulations. The first manipulation was whether the two participants were performing the task together, or whether the participants were co-present but performed the task with a confederate. The second manipulation was whether the participants were positioned facing each other or back to back. The analysis revealed that the postural activity of the two participants was more similar when performing the puzzle task together (i.e. conversing with each other) compared to when performing the task with the confederate. Surprisingly, the interpersonal postural dynamics was not influenced by vision, in that the same magnitude of recurrent activity was observed irrespective of whether the participants could see each other or not. Thus, the findings not only demonstrated how an individual's postural dynamics are spontaneously influenced by interactions with other conspecifics, but also how conversation alone can couple the behavioral dynamics of interacting individuals.

The fact that the physical and informational interactions that characterize social interaction operate to shape behavior (often spontaneously and without awareness) means that the behavioral dynamics of social activity is inherently interaction dominant. In addition to the postural work of Shockley *et al.* (2003), other studies investigating various forms of social movement coordination have produced findings that demonstrated that the dynamics of social behavior is interaction dominant (see Riley, Richardson, Shockley, and Ramenzoni, 2011; Richardson, Marsh, and Schmidt, 2010; Schmidt and Richardson, 2008). The implication is that co-acting individuals form a synergy, whereby the behavioral order of the individuals involved is enslaved by the functional order of the group or team as a whole. Accordingly, the behavioral

performance of interacting individuals is not simply an additive function of each individual's cognitive or behavioral capabilities and, moreover, cannot be understood by studying the individuals in isolation from each other or the social setting. Ramenzoni (2008) highlighted this point, using cross-recurrence analysis to demonstrate how the informational interaction that occurs during joint action results in the dimensional compression of each individual's behavioral degrees of freedom and the formation of a low-dimensional reciprocally compensating synergy. Similar findings have been made by Richardson, Dale, and colleagues in studies investigating social eye coordination and language comprehension (Richardson, Dale, and Tomlinson, 2009). Using categorical cross-recurrence analysis, they have demonstrated across several studies that a shared task context results in synergistic eye movements and that the coordinated stability of such eye movements reflects how well two people comprehend each other (Richardson and Dale, 2005), the strength of their shared knowledge and how much two people converge in language use (Richardson, Dale, and Spivey, 2007).

With respect to $1/f$ scaling and the fractal nature of social behavior, Delignières *et al.* (2004) have demonstrated that fractal processes underlie the dynamics of self-esteem and physical self. Twice a day, for 512 consecutive days, they collected data about the global self-esteem of four individuals. Consistent with a conception of self-perception as an emergent product of an interaction-dominant dynamical system, an analysis of the resulting time series found converging evidence of $1/f$ scaling in the behavioral series. At a more local level, Malone and colleagues (Malone, Castillo, Holden, Kloos, and Richardson, 2013) recently employed a social Simon stimulus-response compatibility task to demonstrate how the mere presence of another actor constrains the fractal variability of an individual's response behavior. The results revealed how the presence of another actor alters a task setting and, as such, the ongoing dynamics of individual behavior (even if the co-present individual is engaged in an independent task). Eiler, Kallen, Harrison, and Richardson (2013) have uncovered preliminary evidence that social stereotypes and gender salience can influence the fractal structure of an individual's cognitive and behavioral performance. Perhaps most compelling is the work by Correll (2008), which has shown that participants who are trying to avoid racial bias show decreased fractal signature in their response latencies in a video game. In light of characterizing social perception and other processes as a system of many intertwined dependencies—as processes of an interaction-dominant dynamical system—these findings suggest that the behavioral fluctuations of socially situated performance reflects the distributed influence of positive and negative perceptions and judgments, and the cultural regulations that define them.

Consequences

The complexity and unpredictability of human behavior has led many cognitive scientists to attempt to understand cognitive systems as complex dynamical systems, and to approach them using complex dynamical analysis. The result of this has been the widespread recognition of interaction-dominant dynamics in the brain and in individual and social cognition. This recognition has consequences both for the nature of cognition and for the practice of cognitive science. Here we focus on consequences concerning modularity and extended cognition. (See Chemero, *in press*.)

Modularity

An *interaction-dominant system* is a highly interconnected system, each of whose components alters the dynamics of many of the others to such an extent that the effects of the interactions are more

powerful than the intrinsic dynamics of the components. In an interaction-dominant system, inherent variability (i.e. fluctuations or noise) of any individual component propagates through the system as a whole, altering the dynamics of the other components. In interaction-dominant systems one cannot treat the components of the system in isolation: because of the widespread feedback in interaction-dominant systems, one cannot isolate components to determine exactly what their contribution is to particular behavior. And because the effects of interactions are more powerful than the intrinsic dynamics of the components, the behavior of the components in any particular interaction-dominant system is not predictable from their behavior in isolation or from their behavior in some other interaction-dominant system. Interaction-dominant systems, in other words, are not *modular*. They are in a deep way *unified* in that the responsibility for system behavior is distributed across all of the components. Given the rapid pace at which cognitive systems have been shown to be interaction dominant in the twenty-first century, there is good reason to think that cognitive systems are not, in general, modular (Anderson *et al.*, 2012; Chemero, in press).

Extended cognition

We have seen that not just neural and brain-body systems are interaction dominant; so too are human-tool cognitive systems and social cognitive systems. Because interaction-dominant systems are unified, we should identify the cognitive systems in these cases with human-tool and social systems as a whole. That is, the cognitive system in question is not encapsulated within an individual brain or even an individual body. This supports the hypothesis of extended cognition. According to the hypothesis of extended cognition, cognitive systems sometimes include portions of the non-bodily environment (Clark and Chalmers, 1998; Chemero 2009). When human-tool or social cognitive systems are complex dynamical systems with interaction-dominant dynamics, they are extended cognitive systems. Moreover, these studies support extended cognition empirically, and not with a priori philosophical argumentation.

References

- Acharya, U. R., Faust, O., Kannathal, N., Chua, T. L., and Laxminarayan, S. (2005). Non-linear analysis of EEG signals at various sleep stages. *Computer Methods and Programs in Biomedicine*, 80, 37–45.
- Anderson, M. L., Richardson, M. J., and Chemero, A. (2012). Eroding the boundaries of cognition: Implications of embodiment. *Topics in Cognitive Science*, 4, 1–14.
- Angus, D., Smith, A., and Wiles, J. (2011). Conceptual recurrence plots: Revealing patterns in human discourse. *IEEE Transactions on Visualization and Computer Graphics*, 18, 988–97.
- Bullmore, E., Long, C., Suckling, J., Fadili, J., Calvert, G., Zelaya, F., Carpenter, T. A., and Brammer, M. (2001). Colored noise and computational inference in neurophysiological (fMRI) time series analysis: Resampling methods in time and wavelet domains. *Human Brain Mapping*, 12, 61–78.
- Camazine, S., Deneubourg, J. L., Franks, N. R., Sneyd, J., Theraulaz, G., and Bonabeau, E. (2001). *Self-organization in biological systems*. Princeton, NJ: Princeton University Press.
- Cavagna, A., Cimarelli, A., Giardina, I., Parisi, G., Santagati, F., Stefanini, F., and Viale, M. (2010). Scale-free correlations in starling flocks. *Proceedings of the National Academy of Sciences of the United States of America*, 107, 11865–70.
- Chemero, A. (2009). *Radical embodied cognitive science*. Cambridge, MA: MIT Press.
- (in press). The architecture of cognition: Rethinking Fodor and Pylyshyn’s systematicity challenge. In P. Calvo Garzon and J. Symons (Eds.), *Systematicity and the cognitive architecture*. Cambridge, MA: MIT Press.
- Cherubini, M.-A. Nüssli, M.-A., and Dillenbourg, P. (2010). This is it!: Indicating and looking in collaborative work at distance. *Journal of Eye Movement Research*, 3, 1–20.
- Clark, A., and Chalmers, D. J. (1998). The extended mind. *Analysis*, 58, 7–19.

- Correll, J. (2008). 1/f noise and effort on implicit measures of racial bias. *Journal of Personality and Social Psychology*, 94, 48–59.
- Dale, R., and Spivey, M. J. (2005). Categorical recurrence analysis of child language. In B. Bara, L. Barsalou, and M. Bucciarelli (Eds.), *Proceedings of the 27th Annual Meeting of the Cognitive Science Society* (pp. 530–35). Mahwah, NJ: Lawrence Erlbaum.
- (2006). Unraveling the dyad: Using recurrence analysis to explore patterns of syntactic coordination between children and caregivers in conversation. *Language Learning*, 56, 391–430.
- Delignières, D., Fortes, M., and Ninot, G. (2004). The fractal dynamics of self-esteem and physical self. *Nonlinear Dynamics in Psychology and Life Science*, 8, 479–510.
- Delignières, D., Ramdani, S., Lemoine, L., Torre, K., Fortes, M., and Ninot, G. (2006). Fractal analysis for short time series: A reassessment of classical methods. *Journal of Mathematical Psychology*, 50, 525–44.
- Dotov, D., Nie, L., and Chemero, A. (2010). A demonstration of the transition from readiness-to-hand to unreadiness-to-hand. *PLoS One*, 5(3), e9433.
- Eiler, B. A., Kallen, R. W., Harrison, S. J., and Richardson, M. J. (2013). Origins of order in joint activity and social behavior. *Ecological Psychology* 25(3), 316–26.
- Freeman, W. J. (2009). Deep analysis of perception through dynamic structures that emerge in cortical activity from self-regulated noise. *Cognitive Neurodynamics*, 3, 105–16.
- Freeman, W. J., Rogers, L. J., Holmes, M. D., and Silbergeld, D. L. (2000). Spatial spectral analysis of human electrocorticograms including the alpha and gamma bands. *Journal of Neuroscience Methods*, 95, 111–21.
- Gallagher, R., and Appenzeller, T. (1999). Beyond reductionism. *Science*, 284, 79.
- Gilden, D. L. (2001). Cognitive emissions of 1/f noise. *Psychological Review*, 108, 33–56.
- (2009). Global model analysis of cognitive variability. *Cognitive Science*, 33, 1441–67.
- Holden, J. G. (2005). Gauging the fractal dimension of response times from cognitive tasks. In M. A. Riley and G. C. Van Orden (Eds.), *Contemporary nonlinear methods for behavioral scientists: A webbook tutorial* (pp. 267–318). Retrieved 8 April 2005, from <http://www.nsf.gov/sbe/bcs/pac/nmbs/nmbs.jsp>
- Kelso, J. A. S. (1995). *Dynamic patterns*. Cambridge, MA: MIT Press.
- (2009). Synergies: Atoms of brain and behavior. In D. Sternad (Ed.), *Progress in motor control* (pp. 83–91). Heidelberg: Springer.
- Kugler, P. N., Kelso, J. A. S., and Turvey, M. T. (1980). On the concept of coordinative structures as dissipative structures, I: Theoretical lines of convergence. In G. E. Stelmach and J. Requin (Eds.), *Tutorials in motor behavior* (pp. 3–47). Amsterdam: North Holland.
- Malone, M., Castillo, R. D., Holden, J. D., Kloos, H., and Richardson, M. J. (2013). Dynamic structure of joint-action stimulus-response activity. In M. Knauff, M. Pauen, N. Sebanz, and I. Wachsmuth (Eds.), *Proceedings of the 35th Annual Conference of the Cognitive Science Society* (pp. 172–77). Austin, TX: Cognitive Science Society.
- Marwan, N. (2008). A historical review of recurrence plots. *European Physical Journal*, 164, 3–12.
- Marwan, N., and Meinke, A. (2002). Extended recurrence plot analysis and its application to ERP data. *International Journal of Bifurcation and Chaos*, 14, 761–71.
- Newton, D. (1994). The perception and coupling of behavior waves. In R. Vallacher and A. Nowak (Eds.), *Dynamical systems in social psychology* (pp. 139–67). San Diego, CA: Academic Press.
- Pannasch, S., Helmert, J. R., Müller, R., and Velichkovsky, B. M. (2012). The analysis of eye movements in the context of cognitive technical systems: Three critical issues. *Lecture Notes in Computer Science: Cognitive Behavioural Systems*, 7403, 19–34.
- Pellecchia, G., Shockley, K., and Turvey, M. (2005). Concurrent cognitive task modulates coordination dynamics. *Cognitive Science*, 29, 531–57.
- Port, R., and van Gelder, T. (1995). *Mind as motion*. Cambridge, MA: MIT Press.
- Ramenzoni, V. C. (2008). *Effects of joint task performance on interpersonal postural coordination* (Unpublished doctoral dissertation). University of Cincinnati, Cincinnati, OH.
- Richardson, D. C., and Dale, R. (2005). Looking to understand: The coupling between speakers’ and listeners’ eye movements and its relationship to discourse comprehension. *Cognitive Science*, 29, 1045–60.
- Richardson, D. C., Dale, R., and Spivey, M. J. (2007). Eye movements in language and cognition. In M. Gonzalez-Marquez, I. Mittelberg, S. Coulson, and M. J. Spivey (Eds.), *Methods in cognitive linguistics* (pp. 328–41). Amsterdam; Philadelphia: John Benjamins.
- Richardson, D. C., Dale, R., and Tomlinson, J. M. (2009). Conversation, gaze coordination, and beliefs about visual context. *Cognitive Science*, 33, 1468–82.

- Richardson, M. J., Dale, R., and Marsh, K. L. (2014). Complex Dynamical Systems in Social and Personality Psychology: Theory, modeling and analysis. In H. T. Reiss and C. M. Judd (Eds.), *Handbook of Research Methods in Social and Personality Psychology, 2nd Edition*. New York, NY: Cambridge University Press.
- Richardson, M. J., Marsh, K. L., Isenhower, R., Goodman, J., and Schmidt, R. C. (2007). Rocking together: Dynamics of intentional and unintentional interpersonal coordination. *Human Movement Science*, 26, 867–91.
- Richardson, M. J., Marsh, K. L., and Schmidt, R. C. (2005). Effects of visual and verbal information on unintentional interpersonal coordination. *Journal of Experimental Psychology: Human Perception and Performance*, 31, 62–79.
- Richardson, M. J., Marsh, K. L., and Schmidt, R. C. (2010). Challenging egocentric notions of perceiving, acting, and knowing. In L. F. Barrett, B. Mesquita, and E. Smith (Eds.), *The mind in context* (pp. 307–33). New York: Guilford.
- Richardson, M. J., Schmidt, R. C., and Kay, B. A. (2007). Distinguishing the noise and attractor strength of coordinated limb movements using recurrence analysis. *Biological Cybernetics*, 96, 59–78.
- Riley, M. A., Balasubramaniam, R., and Turvey, M. T. (1999) Recurrence quantification analysis of postural fluctuations. *Gait and Posture*, 9, 65–78.
- Riley, M. A., Richardson, M. J., Shockley, K., and Ramenzoni, V. C. (2011). Interpersonal synergies. *Frontiers in Psychology*, 2(38), 1–7.
- Schmidt, R. C., and Richardson, M. J. (2008). Dynamics of interpersonal coordination. In A. Fuchs and V. Jirsa (Eds.), *Coordination: Neural, behavioural and social dynamics* (pp. 281–308). Heidelberg: Springer.
- Shockley, K. D., Baker, A. A., Richardson, M. J., and Fowler, C. A. (2007). Verbal constraints on interpersonal postural coordination. *Journal of Experimental Psychology: Human Perception and Performance*, 33, 201–8.
- Shockley, K., Santana, M. V., and Fowler, C. A. (2003). Mutual interpersonal postural constraints are involved in cooperative conversation. *Journal of Experimental Psychology: Human Perception and Performance*, 29, 326–32.
- Stephen, D., Dixon, J., and Isenhower, R. (2009). Dynamics of representational change: Entropy, action, cognition. *Journal of Experimental Psychology: Human Perception and Performance*, 35, 1811–22.
- Stephen, D. G., and Mirman, D. (2010). Interactions dominate the dynamics of visual cognition. *Cognition*, 115, 154–65.
- Thelen, E., and Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge, MA: MIT Press.
- Van Orden, G. C., Holden, J. G., and Turvey, M. T. (2003). Self-organization of cognitive performance. *Journal of Experimental Psychology: General*, 132, 331–50.
- Van Orden, G. C., Kloos, H., and Wallot, S. (2011). Living in the pink: intentionality, wellbeing, and complexity. In C. A. Hooker (Ed.), *Philosophy of complex systems: Handbook of the philosophy of science* (pp. 639–84). Amsterdam: Elsevier.
- Warlaumont, A. S., Oller, D. K., Dale, R., Richards, J. A., Gilkerson, J., and Dongxin, X. (2010). Vocal interaction dynamics of children with and without autism. In S. Ohlsson and R. Catrambone (Eds.), *Proceedings of the 32nd Annual Meeting of the Cognitive Science Society* (pp. 121–26). Austin, TX: Cognitive Science Society.
- Zbilut, J. P., Thomasson, N., and Webber, C. L. (2002). Recurrence quantification analysis as a tool for nonlinear exploration of nonstationary cardiac signals. *Medical Engineering & Physics*, 24, 53–60.

5

THE ROLE OF THE MOTOR SYSTEM IN COGNITIVE FUNCTIONS

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Cognitive embodiment refers to the hypothesis that cognitive processes of all kinds are rooted in perception and action. Recent findings in cognitive neuroscience revealed that the motor cortex, long confined to the mere role of action programming and execution, in fact, plays a crucial role in complex cognitive abilities.

The motor cortex, also defined as the agranular frontal cortex, is formed by a mosaic of at least seven anatomically and functionally distinct areas that appear to play different roles in motor control. Five of these areas receive their predominant cortical input from the parietal lobe, have a direct access to the spinal cord and have direct connections with the primary motor area.

The posterior parietal cortex was classically considered as a large association region into which information from different sensory modalities would converge to construct a single spatial map of the world. This map would be used for all purposes, e.g. walking, reaching objects, or describing a scene verbally. Lesion of this lobe and, in particular, of the inferior parietal lobule, produces a series of spatial deficits ranging from spatial distortions to spatial neglect. This view has been seriously challenged by a series of anatomical and functional data showing that the posterior parietal cortex is constituted by a multiplicity of architectonically and functionally defined areas, each of them involved in the analysis of different aspects of sensory information. Given the strong and specific connections of these parietal areas with the motor cortex, sensory information is then transformed into action (sensorimotor transformation). As a consequence, it is now widely accepted that there is not one single multi-purpose area for perception of space, rather the brain constructs multiple space representations that may be related to a specific class of actions (see Rizzolatti, Fadiga, Fogassi, and Gallese, 1997; Rizzolatti, Fogassi, and Gallese, 1997; Colby and Goldberg, 1999). Typically, each premotor area receives strong afferents from a single parietal area, and parietal and motor areas linked by predominant connections may share common functional properties. Thus, the parietal and premotor areas form a series of anatomical circuits largely independent of one another. In this chapter, parietofrontal circuits involving parietal visual areas, possibly involved in different aspects of visuomotor transformations for action, will be examined in more detail.

The first parietofrontal circuit we consider is constituted by the ventral premotor area F4 and the ventral intraparietal (VIP) area. Most neurons in this circuit discharge in association with

movements of the head or the arm (Gentilucci *et al.*, 1988). In particular, they discharge during the execution of specific actions, such as movements toward the mouth, or when the arm is moved toward a given spatial location. Furthermore, a large proportion of them respond to sensory stimuli. In particular, bimodal neurons respond both to visual three-dimensional stimuli and to tactile stimuli mostly applied to the face or arm (Gentilucci *et al.*, 1988; Graziano, Yap, and Gross, 1994; Fogassi *et al.*, 1996). Visual receptive fields (RFs) are formed by tridimensional portions of space located around the animal. They are generally limited in depth (from a few to about 40 centimeters) and almost always originate from the skin, thus forming an extension in space of the tactile RFs. Visual responses are very often selective for stimuli moving toward the tactile RFs and do not depend on the retinal position of the stimulus. Visual RFs remain anchored to the tactile ones regardless of gaze position, therefore, the VIP-F4 circuit seems to be involved in encoding peripersonal space according to a body-part-centered frame of reference and in transforming object locations into appropriate movements toward them. Furthermore, moving stimuli are not required to trigger F4 visual responses. In fact, Graziano, Hu, and Gross (1997) reported that F4 neurons continue to fire when, unknown to the monkey, the stimulus previously presented has been withdrawn, and the monkey “believes” that it is still near its body. Space representation in the premotor cortex can be generated, therefore, not only as a consequence of an external stimulation but also internally on the basis of previous experience. The interpretation of this result (Rizzolatti, Fadiga, *et al.*, 1997; Rizzolatti, Fogassi, *et al.*, 1997) is that the discharge of neurons reflects a potential action, a motor schema (Arbib, 1981; Jeannerod, Arbib, Rizzolatti, and Sakata, 1995), directed toward a particular spatial location (motor space). The presentation of a visual stimulus or the memory of its location (Graziano *et al.*, 1997) would automatically evoke one of these schemata, which, regardless of whether it is executed, maps the stimulus position in motor terms.

The second parietofrontal circuit involves the frontal eye field (FEF) region, in the prearcuate cortex, and the lateral intraparietal (LIP) area. The LIP-FEF circuit contains three main classes of neurons: neurons responding to visual stimuli (visual neurons), neurons firing in association with eye movements (movement neurons), and neurons with both visual- and movement-related activity (visuomovement neurons) (Andersen, Essick, and Siegel, 1985; Andersen, Bracewell, Barash, Gnadt, and Fogassi, 1990; Andersen and Gnadt, 1989; Barash, Bracewell, Fogassi, Gnadt, and Andersen, 1991; Bruce, 1988; Bruce and Goldberg, 1985; Goldberg and Segraves, 1989). Neurons responsive to visual stimuli respond vigorously to stationary light stimuli and their RFs are usually large. Movement-related neurons fire in relation to ocular saccades, most of them discharging before the saccade onset. Visuomovement neurons have both visual- and saccade-related activity. Visual RFs and “motor” fields are in register, that is, the visual RF corresponds to the end point of the effective saccade. Visual responses in both LIP and FEF neurons are coded in retinotopic coordinates (Andersen and Gnadt, 1989; Goldberg and Segraves, 1989). In other words, their RFs have a specific position on the retina in reference to the fovea. When the eyes move, the RF also moves. Most LIP neurons have, however, an important property. The intensity of their discharge is modulated by the position of the eye in the orbit (orbital effect). Now, if the position of the RF on the retina and the position of the eye in the orbit are both known, one can reconstruct the position of the stimulus in spatial (craniocentric) coordinates. This possibility may allow the LIP-FEF circuit to use eye position and retinotopic information for calculating an absolute position in space and for programming eye movements (Andersen and Mountcastle, 1983; Andersen *et al.*, 1985; Brothie, Andersen, Snyder, and Goodman, 1995).

If one compares the properties of the LIP-FEF circuit with those of the VIP-F4 circuit, some analogies are immediately evident. Both circuits code space specifically for a particular motor

goal: eye movements in the case of the LIP-FEF circuit, body-part movements in the case of the VIP-F4 circuit. The differences possibly concern the different types of movements they control and the different sensory demands that eye movements and body-part movements pose. The way in which space is coded in the two circuits follows the same logic. A rather simple system based on retinotopic neurons, calculating also eye position, is sufficient for programming eye movements that are executed under the same load condition and, therefore, are stereotyped. The organization of body-part movements, which are characterized by a large variability in terms of load, speed and degree of freedom, requires multiple different frames of references. The difference between the properties of the LIP-FEF circuit, on one hand, and the VIP-F4 circuit, on the other, is probably a cue for understanding why there is no multi-purpose space map: the various motor effectors need different information and have different sensory requests and these cannot be provided by a unique map.

Therefore, this description of the neuronal representation of space coding seems to reflect a division of the space on the basis of the potential actions that can be performed in it. The space coded by the VIP-F4 circuit, and termed peripersonal space, is a space in which objects can be grasped and manipulated directly by the unaided use of the arm and the hand, and where the actions can lead to some consequence. Objects located beyond this space, the space coded by the LIP-FEF circuit and termed extrapersonal space, cannot normally be reached but only smelled, heard or seen. Yet, what happens when the unreachable space becomes reachable because of the use of a tool? Iriki, Tanaka, and Iwamura (1996) trained macaques to retrieve distant objects using a rake. In these monkeys, neuronal activity was recorded from the intraparietal cortex, where somatosensory and visual information is integrated. Neurons responding to both somatosensory and visual stimulation, namely “bimodal neurons,” were analyzed. Results showed that after the training, these neurons showed a visual receptive field including the entire length of the rake or covering the expanded accessible space. Therefore, it seems that the peripersonal space is not defined by metrical parameters (i.e. the length of our effectors) but by functional ones: if I am able “to do” something in a space then that becomes my peripersonal space. Inspired by these experiments, several researchers have investigated the behavioral effects of tool use in humans. These studies aimed to identify whether tool-assisted reaching for far stimuli would produce similar behavioral effects as direct reaching for nearby stimuli with the hands alone. Berti and Frassinetti (2000) examined the effect of tool use in a brain-damaged patient, whose neglect selectively affected the peripersonal space. When requested to show the midpoint of a drawn line, she put her mark further towards the right from the objective midpoint. However, when lines were presented in the extrapersonal space and she was requested to use a laser pointer, her performance was almost flawless. By contrast, when a long stick was used for the same far-line bisection, she showed a rightward bias again. One difference between a laser pointer and a long stick is their different capacity to be used in actions in the far space. The laser pointer simulates the eyes’ behavior: it is possible to focus it on a precise position of the far space but only to indicate it. In contrast, the stick simulates a finger behavior which is able to modify the state of the selected space region. For example, with some training, the use of a stick may allow the individual to turn on the light switch on the far wall, while the laser pointer does not permit this. The results of the Berti and Frassinetti (2000) experiment support the idea that when the stick made far space reachable, this became automatically coded by a neural network selective for peripersonal space where neglect was selectively present in the patient. Studies of crossmodal extinction in brain-damaged patients (Farnè and Làdavas, 2000; Maravita, Husain, Clarke, and Driver, 2001), of crossmodal congruency in normal participants (Maravita, Spence, Kennett, and Driver, 2002), of modulation of auditory peripersonal space during mouse use (Bassolino, Serino, Ubaldi, and Làdavas, 2010), and of

pseudo-neglect in real (Longo and Lourenco, 2006) and virtual environments (Gamberini, Seraglia, and Priftis, 2008) also support the view that tool use can modulate peripersonal space.

The last parietofrontal circuit involved in visuomotor transformations for action we consider is formed by the ventral premotor area F5 and the anterior intraparietal area. This is surely the most famous circuit among the three, possibly because the functional properties of its neurons are immediately interpreted as evidence of how cognitive processes may be rooted in perception and action. This circuit contains, among others, the so-called mirror neurons: a mirror neuron is a neuron that fires both when an animal acts and when the animal observes the same action performed by another (di Pellegrino, Fadiga, Fogassi, Gallese, and Rizzolatti, 1992; Gallese, Fadiga, Fogassi, and Rizzolatti, 1996). Thus, the neuron “mirrors” the behavior of the other, as though the observer were itself acting. Many researchers in cognitive neuroscience and cognitive psychology argue that mirror neurons may be important for understanding the actions of other people, and for learning new skills by imitation (Rizzolatti and Craighero, 2004). Some researchers also speculate that mirror systems may simulate observed actions, and thus contribute to theory of mind skills (Keysers and Gazzola, 2006) while others relate mirror neurons to speech abilities (Fadiga, Craighero, Buccino, and Rizzolatti, 2002; Théoret and Pascual-Leone, 2002) or to the human capacity to share emotions (Iacoboni, 2009).

In order to be triggered by visual stimuli, mirror neurons require an interaction between a biological effector (hand or mouth) and an object. The sight of an object alone, of an agent mimicking an action, of an agent performing an action with a tool (unless a long training is made, see Ferrari, Rozzi, and Fogassi, 2005) or of an individual making intransitive gestures are all ineffective. The type of object has no influence (grasping a piece of food or a geometric solid produces responses of the same intensity). Presenting widely different visual stimuli, all representing the same action, is equally effective (the same grasping mirror neuron responds to a human hand or to a monkey hand grasping an object). Similarly, the response is typically not affected if the action is done near or far from the monkey. It is also of little importance for neuron activation if the observed action is eventually rewarded (Gallese *et al.*, 1996). Some mirror neurons (strictly congruent) fire when the observed and executed motor acts are the same (for example, grasping with precision grip), whereas others (broadly congruent) fire when the observed motor act has the same goal as the executed motor act (for example, grasping), but can be achieved in a different way (for example, with both precision and whole-hand grips) (Rizzolatti, Fogassi, and Gallese, 2001). To activate mirror neurons, complete visual information is not necessary: some of them fire in response to actions, the final parts of which are hidden from view (Umiltà *et al.*, 2001). Furthermore, some mirror neurons respond not only to the sight of an action but also to the sound of an action (audiovisual mirror neurons, see Kohler *et al.*, 2002). In addition, so-called mouth mirror neurons have been reported, responsive to the observation of lip-smacking and communicative actions (Ferrari, Gallese, Rizzolatti, and Fogassi, 2003). By analyzing the characteristics of the stimuli evoking the activity of mirror neurons it appears that the only unifying parameter is the presence of the perceived action in the monkey’s motor repertoire. Indeed, a monkey in the forest would never simulate grasping an absent fruit, nor would it ever use pliers for peeling a banana. The monkey has no reason to execute those actions; they represent actions without any goal for the monkey. On the other side, the monkey may grasp either a fruit or a stone, it may decide to use a precision or a whole-hand grip to grasp something, it knows that if a mate is on a fruit tree and moves its hand behind a leaf then it is likely going to grab something, and it knows as well that when it breaks a peanut it will hear a contingent and specific noise. Furthermore, the monkey knows that when it has the intention to engage a mate in friendly interactions it has to lip-smack. Each of these actions has a purpose for the monkey: they all represent goal-related actions for the monkey.

Therefore, what is defining the activity of mirror neurons is not, as some claim, simply the presence of a transitive action, i.e. an action performed towards an object. A lip-smack is an intransitive action. However, lip-smacking is an action that the monkey typically performs to reach a specific goal and, consequently, it is part of its motor repertoire.

From these considerations it seems that the mirror neuron system works as a modality to encode goal-directed actions, just as the auditory system works to encode a sequence of waves of pressure that propagates through a compressible medium (i.e. a sound). Whenever a cue relative to an action is perceived the system is activated: whether it is the sight of someone who breaks a peanut, or the sound of someone breaking the peanut, or the sight of someone who puts a hand inside a bag where I know there are some peanuts. However, if the monkey knows that the peanut bag is empty, the mirror system is not activated (Umiltà *et al.*, 2001). For the monkey “to put a hand inside an empty bag” is not an action, because it serves no purpose. The mirror system does not encode movements which are not part of the individual’s motor repertoire, exactly as the auditory system does not encode electromagnetic radiation (i.e. a light). Possibly, movements which are not part of the individual’s motor repertoire are elaborated by the visual system as any other visual stimulus and are recognized and categorized exactly as would be stimuli such as a moving car or a tree that bends on a windy day (see also Shapiro, 2009).

There is convincing evidence that an action observation-action execution mirror system also exists in humans. This evidence comes from brain imaging, transcranial magnetic stimulation, electroencephalography, magnetoencephalography and psychophysical studies (see Rizzolatti and Craighero, 2004). However, the properties of the human mirror system differ dramatically from those of the monkey. In fact, this system may be active during the observation of both transitive and intransitive (non-object-directed) actions (Fadiga, Fogassi, Pavesi, and Rizzolatti, 1995; Brass, Bekkering, Wohlschläger, and Prinz, 2000; Buccino *et al.*, 2001) and during observation of pantomimes (Fadiga *et al.*, 2006). These differences, however, are canceled when we consider that humans commonly use intransitive actions and pantomimes to communicate or clarify concepts or feelings and sensations. This practice may have emerged from the capacity for abstraction, which allows humans to be free from the contingent relation with the objects (Fadiga *et al.*, 2006; Fadiga, Craighero, and D’Ausilio, 2009). Therefore, for humans both intransitive actions and pantomimes are goal-related actions and probably for this reason they are able to activate the human mirror system.

But for what reason do some primates possess a dedicated system to encode goal-directed actions? Why is it not sufficient to merely use the visual system? One possibility is to have the opportunity to reuse the accumulated knowledge regarding the consequences of our own actions and consequently to have the ability to anticipate and predict the outcome of others’ actions, enabling both collaborative or conflicting behaviors which form the basis of a social community (Rizzolatti *et al.*, 2001). There is much experimental evidence showing the possibility that the mirror system is involved in action prediction (Gangitano, Mottaghy, and Pascual-Leone, 2004; Montagna, Cerri, Borroni, and Baldissera, 2005; Craighero *et al.*, 2008); however, it is common knowledge that having the skill to perform an action makes one better at predicting and anticipating that action in others (Casile and Giese, 2006). This evidence is particularly clear in elite athletes as demonstrated by an experiment in which skilful basketball players, expert watchers (coaches and sports journalists) and novices were asked to judge the fate of free-throw shots at a basket (Aglioti, Cesari, Romani, and Urgesi, 2008). Participants were presented with movies showing free-throw basket shots performed by a professional basketball player. In half of the movies the ball landed in the basket and in the other half it did not. Video presentation was interrupted at 10 different durations (minimum 426 milliseconds; maximum 1,623 milliseconds). Participants were asked to choose among three possible

responses, namely, “Ball in,” “Ball out,” and “I don’t know.” Results showed that professional basketball players predict the outcome of free-throw shots earlier and more accurately than people who had no direct motor experience with a basketball. Furthermore, in the second part of the experiment the covert simulation of the observed action was tested by using transcranial magnetic stimulation technique and results showed that only athletes displayed a time-specific motor activation during observation of erroneous free throws. Indeed, the athletes showed motor activation that would appear to correct for the error in the shooter’s release. Unconscious awareness of such activation perhaps underlies the athletes’ superior ability to predict the success of the free throw.

Another possible function of a dedicated system for coding actions on the basis of accumulated motor knowledge is to have the opportunity to learn new motor abilities. Likely this function belongs exclusively to the human mirror system since it requires the possibility to interpret as goal-directed even strange movements performed by a dance teacher during a lesson. This opportunity would allow the activation of the human mirror system and the retrieval of the sensorimotor representation of a similar movement aiming at the same goal (e.g. “stand with hips turned out, heels touching together creating as close to a straight line with the feet as possible” may just be translated into: “stand with heels almost touching and feet turned outwards”). In this way, step by step, new motor abilities are acquired and new sensorimotor representations are generated permitting a more precise perception of the observed action. This hypothesis is supported by many different experimental results showing that mirror activation is greater for familiar actions but that even unfamiliar actions can cause it (Calvo-Merino, Glaser, Grezes, Passingham, and Haggard, 2005; Buccino *et al.*, 2004), that motor expertise modulates the activation of the human mirror system during the observation of dance moves, and that this activation is higher in individuals who had direct motor experience of the observed dance moves even when the experimenter controlled for the effect of visual familiarity with the moves (Calvo-Merino, Grezes, Glaser, Passingham, and Haggard, 2006). Moreover, learning complex dance patterns modulates neural motor activity during the observation of practiced as compared with visually familiar, but unpracticed, movements (Cross, Hamilton, and Grafton, 2006; Cross, Kraemer, Hamilton, Kelley, and Grafton, 2009).

The functional properties of the neurons present in parietofrontal circuits involved in visuo-motor transformations for action we reviewed in this chapter clearly indicate that the motor system plays a crucial role in complex cognitive abilities such as space coding, motor learning and prediction of others’ actions. Furthermore, we considered a series of experiments both in monkeys and in humans whose results are at odds with the traditional cognitivist view that percepts are built from elementary sensory information via a series of progressively more and more complex representations, suggesting the artificiality of a rigid wall between sensory and motor representations.

References

- Aglioti, S. M., Cesari, P., Romani, M., and Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. *Nature Neuroscience*, 11(9), 1109–16.
- Andersen, R. A., Bracewell, R. M., Barash, S., Gnadt, J. W., and Fogassi, L. (1990). Eye position effects on visual, memory, and saccade-related activity in areas LIP and 7a of macaque. *Journal of Neuroscience*, 10, 1176–96.
- Andersen, R. A., Essick, G. K., and Siegel, R. M. (1985). Encoding spatial location by posterior parietal neurons. *Science*, 230, 456–58.
- Andersen, R. A., and Gnadt, J. W. (1989). Role of posterior parietal cortex in saccadic eye movements. In R. Wurtz and M. Goldberg (Eds.), *The neurobiology of saccadic eye movements* (Reviews of Oculomotor Research, Vol. 3). Amsterdam: Elsevier.

- Andersen, R. A., and Mountcastle, V. B. (1983). The influence of the angle of gaze upon the excitability of the light-sensitivity neurons of the posterior parietal cortex. *Journal of Neuroscience* 3, 532–48.
- Arbib, M. A. (1981). Perceptual structures and distributed motor control. in V. B. Brooks (Ed.), *Handbook of physiology, section 1: The nervous system, Vol. II, Motor control, Pt. 1*. Bethesda, MD: American Physiological Society.
- Barash, S., Bracewell, R. M., Fogassi, L., Gnadt, J. W., and Andersen, R. A. (1991). Saccade-related activity in the lateral intraparietal area, II: Spatial properties. *Journal of Neurophysiology*, 66, 1109–24.
- Bassolino, M., Serino, A., Ubaldi, S., and Làdavas, E. (2010). Everyday use of the computer mouse extends peripersonal space representation. *Neuropsychologia*, 48(3), 803–11.
- Berti, A., and Frassinetti, F. (2000). When far becomes near: Remapping of space by tool use. *Journal of Cognitive Neuroscience*, 12(3), 415–20.
- Brass, M., Bekkering, H., Wohlschläger, A., and Prinz, W. (2000). Compatibility between observed and executed finger movements: Comparing symbolic, spatial, and imitative cues. *Brain and Cognition*, 44(2), 124–43.
- Brochier, P. R., Andersen, R. A., Snyder, L. H., and Goodman, S. J. (1995). Head position signals used by parietal neurons to encode locations of visual stimuli. *Nature*, 375, 232–35.
- Bruce, C. J. (1988). Single neuron activity in the monkey's prefrontal cortex. In P. Rakic and W. Singer (Eds.), *Neurobiology of neocortex* (pp. 297–329). New York: Wiley.
- Bruce, C. J., and Goldberg, M. E. (1985). Primate frontal eye field, I: Single neurons discharging before saccades. *Journal of Neurophysiology*, 53, 603–35.
- Buccino, G., Binkofski, F., Fink, G. R., Fadiga, L., Fogassi, L., Gallese, V., Seitz, R. J., Zilles, K., Rizzolatti, G., and Freund, H. J. (2001). Action observation activates premotor and parietal areas in a somatotopic manner: An fMRI study. *European Journal of Neuroscience*, 13(2), 400–4.
- Buccino, G., Lui, F., Canessa, N., Patteri, I., Lagravinese, G., Benuzzi, F., Porro, C. A., and Rizzolatti, G. (2004). Neural circuits involved in the recognition of actions performed by nonconspecifics: An fMRI study. *Journal of Cognitive Neuroscience*, 16, 114–26.
- Calvo-Merino, B., Glaser, D. E., Grezes, J., Passingham, R. E., and Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral Cortex*, 15, 1243–49.
- Calvo-Merino, B., Grezes, J., Glaser, D. E., Passingham, R. E., and Haggard, P. (2006). Seeing or doing? Influence of visual and motor familiarity in action observation. *Current Biology*, 16, 1905–10.
- Casile, A., and Giese, M. A. (2006). Nonvisual motor training influences biological motion perception. *Current Biology*, 16, 69–74.
- Colby, C. L., and Goldberg, M. E. (1999). Space and attention in parietal cortex. *Annual Review of Neuroscience*, 22, 319–49.
- Craigheero, L., Bonetti, F., Massarenti, L., Canto, R., Fabbri Destro, M., and Fadiga, L. (2008). Temporal prediction of touch instant during observation of human and robot grasping. *Brain Research Bulletin*, 75 (6), 770–74.
- Cross, E. S., Hamilton, A. F., and Grafton, S. T. (2006). Building a motor simulation de novo: Observation of dance by dancers. *Neuroimage*, 31, 1257–67.
- Cross, E. S., Kraemer, D. J., Hamilton, A. F., Kelley, W. M., and Grafton, S. T. (2009). Sensitivity of the action observation network to physical and observational learning. *Cerebral Cortex*, 19(2), 315–26.
- di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., and Rizzolatti, G. (1992). Understanding motor events: A neurophysiological study. *Experimental Brain Research*, 91(1), 176–80.
- Fadiga, L., Craigheero, L., Buccino, G., and Rizzolatti, G. (2002). Speech listening specifically modulates the excitability of tongue muscles: A TMS study. *European Journal of Neuroscience*, 15(2), 399–402.
- Fadiga, L., Craigheero, L., and D'Ausilio, A. (2009). Broca's area in language, action, and music. *Annals of the New York Academy of Sciences*, 1169, 448–58.
- Fadiga, L., Craigheero, L., Destro, M. F., Finos, L., Cotillon-Williams, N., Smith, A. T., and Castiello, U. (2006). Language in shadow. *Social Neuroscience*, 1(2), 77–89.
- Fadiga, L., Fogassi, L., Pavesi, G., and Rizzolatti, G. (1995). Motor facilitation during action observation: A magnetic stimulation study. *Journal of Neurophysiology*, 73(6), 2608–11.
- Farnè, A., and Làdavas, E. (2000). Dynamic size-change of hand peripersonal space following tool use. *NeuroReport*, 11, 1645–49.
- Ferrari, P. F., Gallese, V., Rizzolatti, G., and Fogassi, L. (2003). Mirror neurons responding to the observation of ingestive and communicative mouth actions in the monkey ventral premotor cortex. *European Journal of Neuroscience*, 17(8), 1703–14.

- Ferrari, P. F., Rozzi, S., and Fogassi, L. (2005). Mirror neurons responding to observation of actions made with tools in monkey ventral premotor cortex. *Journal of Cognitive Neuroscience*, 17(2), 212–26.
- Fogassi, L., Gallese, V., Fadiga, L., Luppino, G., Matelli, M., and Rizzolatti, G. (1996). Coding of peripersonal space in inferior premotor cortex (area F4). *Journal of Neurophysiology*, 76, 141–57.
- Gallese, V., Fadiga, L., Fogassi, L., and Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain*, 119(2), 593–609.
- Gamberini, L., Seraglia, B., and Priftis, K. (2008). Processing of peripersonal and extrapersonal space using tools: Evidence from visual line bisection in real and virtual environments. *Neuropsychologia*, 46(5), 1298–1304.
- Gangitano, M., Mottaghy, F. M., and Pascual-Leone, A. (2004). Modulation of premotor mirror neuron activity during observation of unpredictable grasping movements. *European Journal of Neuroscience*, 20(8), 2193–2202.
- Gentilucci, M., Fogassi, L., Luppino, G., Matelli, M., Camarda, R., and Rizzolatti, G. (1988). Functional organization of inferior area 6 in the macaque monkey, I: Somatotopy and the control of proximal movements. *Experimental Brain Research*, 71, 475–90.
- Goldberg, M. E., and Segraves, M. A. (1989). The visual and frontal cortices. *Reviews of Oculomotor Research*, 3, 283–313.
- Graziano, M. S., Hu, X. T., and Gross, C. G. (1997). Coding the locations of objects in the dark. *Science*, 277(5323), 239–41.
- Graziano, M. S. A., Yap, G. S., and Gross, C. G. (1994). Coding of visual space by premotor neurons. *Science*, 266, 1054–57.
- Iacoboni, M. (2009). Imitation, empathy, and mirror neurons. *Annual Review of Psychology*, 60, 653–70.
- Iriki, A., Tanaka, M., and Iwamura, Y. (1996). Coding of modified body schema during tool use by macaque postcentral neurones. *Neuroreport*, 7(14), 2325–30.
- Jeannerod, M., Arbib, M. A., Rizzolatti, G., and Sakata, H. (1995). Grasping objects: The cortical mechanisms of visuomotor transformation. *Trends in Neurosciences*, 18, 314–20.
- Keysers, C., and Gazzola, V. (2006). Towards a unifying neural theory of social cognition. *Progress in Brain Research*, 156, 379–401.
- Kohler, E., Keysers, C., Umiltà, M. A., Fogassi, L., Gallese, V., and Rizzolatti, G. (2002) Hearing sounds, understanding actions: action representation in mirror neurons. *Science*, 297, 846–48.
- Longo, M. R., and Lourenco, S. F. (2006). On the nature of near space: Effects of tool use and the transition to far space. *Neuropsychologia*, 44(6), 977–81.
- Maravita, A., Husain, M., Clarke, K., and Driver, J. (2001). Reaching with a tool extends visual-tactile interactions into far space: Evidence from cross-modal extinction. *Neuropsychologia*, 39, 580–85.
- Maravita, A., Spence, C., Kennett, S., and Driver, J. (2002). Tool-use changes multimodal spatial interactions between vision and touch in normal humans. *Cognition*, 83, 25–34.
- Montagna, M., Cerri, G., Borroni, P., and Baldissera, F. (2005). Excitability changes in human corticospinal projections to muscles moving hand and fingers while viewing a reaching and grasping action. *European Journal of Neuroscience*, 22(6), 1513–20.
- Rizzolatti, G., and Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience*, 27, 169–92.
- Rizzolatti, G., Fadiga, L., Fogassi, L., and Gallese, V. (1997). The space around us. *Science*, 277(5323), 190–91.
- Rizzolatti, G., Fogassi, L., and Gallese, V. (1997). Parietal cortex: From sight to action. *Current Opinion in Neurobiology*, 7, 562–67.
- Rizzolatti, G., Fogassi, L., and Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews: Neuroscience*, 2, 661–70.
- Shapiro, L. (2009). Making sense of mirror neurons. *Synthese*, 167, 439–56.
- Théoret, H., and Pascual-Leone, A. (2002). Language acquisition: Do as you hear. *Current Biology*, 12(21), R736–37.
- Umiltà, M. A., Kohler, E., Gallese, V., Fogassi, L., Fadiga, L., Keysers, C., and Rizzolatti, G. (2001). I know what you are doing: A neurophysiological study. *Neuron*, 31(1), 155–65.

6

EMBEDDED AND SITUATED COGNITION

Michael Dawson

Embodied cognitive science reacts against more established traditions within cognitive science (Clark, 1997; Dawson, 2013; Dawson, Dupuis, and Wilson, 2010; Shapiro, 2011). Shapiro has identified three main themes that separate the embodied approach from these traditions. *Conceptualization* is the notion that an agent's understanding of its world depends critically upon the nature of the agent's body. *Replacement* is the idea that an agent's interactions with its world replace the need for internal mental representations. *Constitution* is the position that an agent's world and body are constituents of (and not merely causally related to) an agent's mind.

The purpose of the current chapter is to explore what is implied when cognitive scientists describe cognition as *embodied*, *embedded*, or *situated* (Chemero, 2009; Clancey, 1997; Clark, 1997, 1999, 2003; Dawson *et al.*, 2010; Dourish, 2001; Shapiro, 2011; Varela, Thompson, and Rosch, 1991). This will be accomplished by contrasting these ideas with some traditional foundations of standard cognitive science (Dawson, 1998). In so doing, issues related to Shapiro's (2011) three themes of conceptualization, replacement, and constitution are developed.

Underdetermination in perception

Humans take visual perception for granted. Our experience is that we simply look at the world and automatically see it in high detail (Noë, 2002, 2004). This is the "video camera theory" of vision. However, failures to develop seeing computers made it apparent that the video camera theory was inadequate. Researchers discovered that the human visual system was effortlessly solving enormously complicated information-processing problems. Primary visual data (the proximal stimulus on the retina) does not contain enough information to determine a unique and correct visual interpretation. That is, a single proximal stimulus is consistent with an infinite number of different interpretations (Marr, 1969). This is called the *problem of underdetermination* or, borrowing a term from the study of language (Chomsky, 1965) the *poverty of the stimulus*. Problems of underdetermination are notoriously difficult to solve, but are apparently solved effortlessly by human visual processing.

How might problems of underdetermination be solved? Standard cognitive science claims that these problems are solved using *unconscious inference* (Bruner, 1957; Helmholtz, 1868/1968; Rock, 1983). According to this hypothesis, perception is identical to cognition; knowledge-driven

inferential processing adds information that disambiguates the proximal stimulus and produces the correct interpretation.

This cognitive view dominates modern theories of perception (Pylyshyn, 2003). To them, sensation provides some of the information used to create a mental model. Next, thinking (e.g. unconscious inference) completes the model's construction by supplementing sensation. Once created, the mental model provides the basis for planning and acting. Thinking therefore stands as a necessary intermediary between sensing and acting, producing the *sense-think-act cycle* that defines the *classical sandwich* (Hurley, 2001).

However, what if the purpose of perception is not to build mental models, but is instead to control actions on the world? Embodied cognitive science replaces the sense-think-act cycle with *sense-act processing* (Brooks, 1999; Clark, 1997; Pfeifer and Scheier, 1999). According to this alternative view, there are *direct* links between sensing and acting. Embodied cognitive science views the brain as a controller, not as a model-builder or a planner. To investigate the implications of this position, consider an example from comparative psychology.

Case study: echolocation

In the traditional sense-think-act cycle, agents are passive receivers of information. In contrast, the sense-act theory of perception proposes that perception is active, because perceivers are constantly exploring their worlds. *Echolocation* is an example of an active sensing system because bats use self-generated energy to probe their environments (Nelson and MacIver, 2006). Many species of bats hunt by emitting ultrasonic sounds and by using ultrasonic echoes to detect target locations. This enables bats to discover and intercept targets as small as fruit flies or mosquitoes from distances of between 50 and 100 centimeters (Griffin, Webster, and Michael, 1960).

There are three definite stages in a bat's use of echolocation to hunt prey (Griffin *et al.*, 1960). In the *search phase*, bats fly relatively straight and emit sounds at a relatively slow rate of repetition. When the bat first detects an insect during the search phase, an *approach phase* begins: the bat turns towards the detected insect, and progressively increases the rate of repetition of its signals, presumably to locate its target more accurately. When the bat is close enough to the insect, it moves into a *terminal phase* and produces sounds at such a high rate that the result is an ultrasonic buzz that enables the bat to close in and capture the quarry.

However, moths do not simply wait to become meals. Moth wing scales absorb sounds at the frequencies of bat ultrasonics, dampening a moth's echo (Zeng *et al.*, 2011). Furthermore, some moths have evolved transducers that permit them to hear bat echolocation signals (Fenton and Fullard, 1979; Roeder and Treat, 1961; Rydell, Jones, and Waters, 1995). As soon as such a signal is heard, a moth will execute a power dive towards the ground; this dive often includes a series of evasive maneuvers that involve tight turns, loops, and climbs (Roeder and Treat, 1961). In addition, some species of moth emit their own ultrasonic sounds. This causes bats to turn away from their prey (Dunning and Roeder, 1965) because the moth's signal indicates that the moth is of a type that is inedible or because the signal actually interferes with bat echolocation (Fenton and Fullard, 1979; Fullard, Simmons, and Saillant, 1994; Hristov and Conner, 2005; Rydell *et al.*, 1995).

The counter-measures developed by moths have themselves been countered by bats, some of whom use ultrasonic frequencies out of the range of moth hearing, or who hunt silently and listen for the sounds generated by their prey (Rydell *et al.*, 1995). Bats also learn from their echolocation encounters, changing their behavior to discriminate one type of target from another (Griffin, Friend, and Webster, 1965). There is a dynamic relationship between a single echolocating bat and an individual moth that hears and attempts to evade its predator.

Situating echolocation

Cyberneticists recognized that agents are intrinsically coupled to their environment, because an agent's actions can change the world, which in turn can influence the agent's future actions, a relation called *feedback* (Ashby, 1956; Wiener, 1948).

A bat that uses echolocation to hunt hearing moths is clearly in a feedback relationship with its environment. The bat's actions – both in terms of its flight and in terms of the sounds that it generates – depend upon the distance between the bat and its prey. Furthermore, when a moth detects this attack, it begins evasive maneuvers, which represents a change in the world caused by the bat's ultrasonic probing. In turn, this change in the world produces changes in the bat's behavior, as it alters its flight path to foil the evasion.

Critically, the coupling between the actions of the bat and the actions of its prey are occurring over drastically short periods of time (Griffin *et al.*, 1960). Bats are usually hunting targets that are less than a meter away, are flying at speeds of 1 to 6 meters/second, and have only a few milliseconds to process the echo from any given target (Horiuchi, 2005). As a result, bat flight is adjusted by neurons that only have enough time to generate one or two action potentials.

One of the motivations behind the hypothesis of sense-act processing is increasing processing speed by eliminating the “thinking bottleneck.” The neuroscience of bat echolocation reveals a circuitry that is consistent with sense-act processing. For instance, auditory processing in the bat brain is tightly coupled with motor processing, particularly with motor circuits responsible for bat vocalizations (Moss and Sinha, 2003). This might reflect a sense-act system for modulating ultrasonic signals as a function of echolocation feedback; we saw earlier that the signals produced by bats vary throughout an attack sequence. Similarly, VLSI (very-large-scale integration) circuits that attempt to model the neural circuitry of echolocation, and use the output of this circuitry to control movements directly, have been successfully developed for autonomously steering robots through complex obstacle courses (Horiuchi, 2005).

Adequate theories of echolocation require considering the coupling between the bat and its world. Bats detect small, moving targets, do so while flying in three dimensions at high speeds, and detect (and react to) changes in target location in a matter of milliseconds. All of these constraints arise from the relationship between the bat and the dynamic world in which it hunts.

To say that an adequate theory of echolocation must take the coupling of a bat and its environment into account is to say that such a theory must be *embedded* or *situated*. When researchers describe cognition as being embedded or situated (Beer, 2003; Clancey, 1993, 1997; Pylyshyn, 2000; Roy, 2005), they emphasize the fact that agents are coupled with a dynamic world (Shapiro, 2011). Because of this, some of the explanatory force of an embedded or situated theory comes from appeals to properties of the world, or to properties of the world-agent interface (Ashby, 1956; Grey Walter, 1963; Simon, 1969).

Underdetermination and embodiment

Standard cognitive scientists have argued (Vera and Simon, 1993, 1994) that they have long cited environmental influences in their theories of cognition, citing Simon's parable of the ant (Simon, 1969) as a famous example of this commitment. However, standard cognitive scientists also admit that they have emphasized the “thinking” within the classical sandwich at the expense of the study of both sensing and acting (Anderson *et al.*, 2004; Newell, 1990). In embedded or situated cognition, the environment is more than just a source of inputs. When an agent is situated, its experience of the world depends crucially upon not only its sensory mechanisms, but also upon the nature of its body and the potential of its body to affect the world. “It is often neglected that the words *animal* and *environment* make an inseparable pair” (Gibson, 1979, p. 8).

Modern embodied cognitive science's position that we must consider the interface between an agent and the world in relation to the agent's body relates to theories developed by other disciplines. Biologist Jakob von Uexküll coined the term *Umwelt* to denote the "island of the senses" produced by the unique way in which an organism is perceptually engaged with its world (Uexküll, 2001). One can only describe an Umwelt by describing the properties of both a world and an agent. Psychologist James Gibson proposed the ecological theory of perception (Gibson, 1966, 1979). Gibson's theory focused upon the coupling between an agent and the world, and emphasized that this coupling depends upon the nature of an agent's body. Gibson argued that the purpose of perception was to deliver *affordances*.

Affordances are the possibilities for action that a particular object permits a particular agent. Affordances require an integral relationship between an object's properties and an agent's abilities to act. Furthermore, an agent's abilities to act depend upon the structure of its body. In short, affordances are defined in relation to an agent's body.

The previous section on situating echolocation argued that if perception is embedded or situated, then a theory of perception must refer to the dynamic coupling between an agent and the world. The implication of the current section is that this theory must also refer to the nature of the agent's body. To provide an example of this, let us return for a moment to bat echolocation.

With echolocation, the difference in time between the echo's arrival to a bat's left and right ears uniquely determines the horizontal position of a prey insect. However, this information is not sufficient to determine the vertical position of the target. How does the bat's echolocation system solve this problem of underdetermination?

One of the notable features of bats is the extravagant shapes of the pinna and tragus of their external ears. Evidence suggests that these amazing ear shapes are important for a bat to determine a target's vertical position. For instance, gluing the tragus of its ear forward severely impairs a bat's vertical discrimination ability (Chiu and Moss, 2007; Lawrence and Simmons, 1982).

Why does the shape of the ear matter? The shape causes returning echoes to strike the ear at different angles of entry, producing specific distortions in the sound signal (Müller, Lu, and Buck, 2008; Obrist, Fenton, Eger, and Schlegel, 1993; Reijnen, Vanderelst, and Peremans, 2010). These distortions provide additional auditory cues that vary systematically with the vertical position of the target (Wotton, Haresign, and Simmons, 1995; Wotton and Simmons, 2000). In other words, the shape of a bat's ear alters sound in such a way that information about a target's vertical dimension is added to the incoming signal.

That the shape of part of a bat's body solves a problem of underdetermination is a radical departure from the claim that cognitive processes are used to deal with the poverty of the stimulus. Indeed, in the case of bat echolocation, it seems as though the bat's body has removed the problem of vertical underdetermination before auditory signals have reached the bat's brain!

Degrees of embodiment

In viewing cognition as embedded or situated, embodied cognitive science emphasizes feedback between an agent and the world. We have seen that this feedback is structured by the nature of an agent's body. This is because an agent's body places constraints on how the world is experienced (Umwelt) as well as on how the world is acted upon (affordance). This in turn suggests that agents with different kinds of bodies can be differentiated in terms of degrees of embodiment (Fong, Nourbakhsh, and Dautenhahn, 2003). Embodiment can be defined as the extent to which an agent can alter its environment. For instance, Fong *et al.* (2003, p. 149) argue

“embodiment is grounded in the relationship between a system and its environment. The more a robot can perturb an environment, and be perturbed by it, the more it is embodied.” In other words, as agents are more embodied, they are immersed in higher degrees of feedback.

Importantly, we must consider degrees of embodiment in the context of an agent’s *Umwelt*. For instance, from the perspective of our *Umwelt*, bats do not seem to be very embodied at all, because they do not (for instance) move large objects around. However, from the perspective of the bat, we have noted that bat echolocation causes dramatic changes in its environment, changing the movements of flying insects that are attempting to avoid predators. Similarly, famous social robots like *Kismet* (Breazeal, 2002) may not appear to be strongly embodied, because they are only heads and have no arms to manipulate the world and no legs to move through it. However, in *Kismet*’s social *Umwelt*, changes in its expression and head posture produce dramatic changes in expression, posture, and vocalizations of humans interacting with the social robot.

The more embodied an agent is, the more interesting are the potential architectures that can be used to account for its cognitive processing. For instance, entomologists have long been interested in explaining how social insects can produce large and complex structures such as termite mounds. These mounds range from 2 to 7 meters in height, (von Frisch, 1974), and a single mound may exist for decades. A colony’s mound extends in space and time far beyond the life expectancy of the individual termites that create it.

One important theory contends that *stigmergy* controls termite mound construction (Grassé, 1959; Theraulaz and Bonabeau, 1999). The term comes from the Greek *stigma*, meaning sting, and *ergon*, meaning work, capturing the notion that the environment is a stimulus that causes particular work (behavior) to occur. Grassé demonstrated that termites’ building behavior is not regulated by the insects themselves, but is instead controlled externally by the mound. That is, the appearance of a local part of the mound serves as a stimulus that causes termites to alter that part of the mound in a particular way. However, if stigmergy is to work, then agents must be embodied to the extent that they can change the world in appropriate ways.

Stigmergy is an example of a novel contribution to cognitive science provided by embodied cognitive science. Control mechanisms that choose which primitive operation or operations to execute at any given time are fundamental to theories of cognition. Typically standard cognitive science internalizes control (e.g. the central executive in models of working memory [Baddeley, 1986]). With concepts like stigmergy, embodied cognitive science counters this standard approach, and explores the possibility that the external world is a fundamental source of control (Downing and Jeanne, 1988; Holland and Melhuish, 1999; Karsai, 1999; Susi and Ziemke, 2001; Theraulaz and Bonabeau, 1999).

It is important to remember, though, that notions like stigmergy are not merely appeals to external sources of information. The degree to which stigmergy controls an agent depends upon the agent’s coupling with the world, and therefore depends upon an agent’s body, as well as the potential changes to the world that agent’s body makes possible. The more embodied an agent is, the more capable it is of altering the world around it, and of modifying the affordances available to it.

Active externalization

In spite of repeated warnings during its formative years (Hayes, Ford, and Agnew, 1994; Miller, Galanter, and Pribram, 1960; Norman, 1980), standard cognitive science has steadfastly under-emphasized the role of the environment. It has been argued (Dawson, 2013) that the root of this stubborn stance is in cognitivism’s reaction against behaviorism; cognitivists were concerned

that behaviorists viewed humans as passive responders to the environment (Gardner, 1984). By rejecting the role of environment, standard cognitivism excluded a central plank of behaviorism. The notion of degrees of embodiment prevents embedded or situated cognition from devolving back into behaviorism. Humans are perhaps the most embodied agents on the planet, in the sense that they actively strive to manipulate their environment (Bronowski, 1973). As a result, humans can exploit their coupling with the world to deliberately extend or externalize their cognitive processes. The use of external structures to support cognition is *cognitive scaffolding* (Clark, 1997).

Research on practical cognition, or mind in action (Scribner, 1985; Scribner and Beach, 1993; Scribner and Tobach, 1997), has revealed that humans are masters at using the world to scaffold everyday problem solving. For example, Scribner discovered that a reliable difference between expert and novice dairy workers was that the former were more likely to use environmental resources to scaffold their activities. Expert workers used the visual appearance of dairy crates to determine how to fill orders of different amounts of dairy products.

The external world not only provides information storage, but may also manipulate stored information. A variety of navigational tools permit the results of computations to simply be inspected after data is recorded on them (Hutchins, 1995). “It seems that much of the computation was done by the tool, or by its designer. The person somehow could succeed by doing less because the tool did more” (Hutchins, 1995, p. 151).

Critically, our ability to alter the environment does not mean that we are decoupled from it. Humans actively manipulate and create their world, but dynamically respond to it too. This means that cognitive scaffolding is not without constraints. Artifacts, equipment, or technologies that provide scaffolding exist at the interface between a person and the world. Successful scaffolding will reflect this embedding, and be successful because it is appropriate to the possible actions available to the person that takes advantage of it. It would seem, then, that an examination of the nature of artifacts that are pervasive in human societies should reveal a great deal about human cognition.

This suggests that embodied cognitive science could flourish as a science of design. Viewing cognitive science in this fashion is not a novel idea. Simon’s (1969) famous monograph *The Sciences of the Artificial* argued that design was central to the study of cognition, and also provided one of the seminal arguments in favor of a science of design. However, Simon viewed the science of design from the perspective of standard cognitive science, describing it as a problem-solving process that searched for optimal designs using representational techniques.

More modern approaches to design (Dourish, 2001; Norman, 1998, 2002; Schön, 1992; Visser, 2006; Winograd and Flores, 1987) are much more sympathetic to the embodied perspective. The relationship between artifacts and agents is central: the more aware an agent is of an artifact’s affordances (and the less aware of the artifact as an object) the better is its design. “A device is easy to use when there is visibility to the set of possible actions, where the controls and displays exploit natural mappings” (Norman, 2002, p. 25). Embodied cognitive science may depart from the standard approach by examining the character of good design to explore the nature of the coupling between agents and environments. “Man – or at least the intellectual component of man – may be relatively simple; most of the complexity of his behavior may be drawn from his environment, from his search for good designs” (Simon, 1969, p. 83).

References

- Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., and Qin, Y. L. (2004). An integrated theory of the mind. *Psychological Review*, 111(4), 1036–60.
- Ashby, W. R. (1956). *An introduction to cybernetics*. London: Chapman & Hall.

- Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.
- Beer, R. D. (2003). The dynamics of active categorical perception in an evolved model agent. *Adaptive Behavior*, 11(4), 209–43.
- Breazeal, C. L. (2002). *Designing sociable robots*. Cambridge, MA: MIT Press.
- Bronowski, J. (1973). *The ascent of man*. London: BBC.
- Brooks, R. A. (1999). *Cambrian intelligence: The early history of the new AI*. Cambridge, MA: MIT Press.
- Bruner, J. S. (1957). On perceptual readiness. *Psychological Review*, 64, 123–52.
- Chemero, A. (2009). *Radical embodied cognitive science*. Cambridge, MA: MIT Press.
- Chiu, C., and Moss, C. F. (2007). The role of the external ear in vertical sound localization in the free flying bat, *Eptesicus fuscus*. *Journal of the Acoustical Society of America*, 121(4), 2227–35.
- Chomsky, N. (1965). *Aspects of the theory of syntax*. Cambridge, MA: MIT Press.
- Clancey, W. J. (1993). Situated action: A neuropsychological interpretation response. *Cognitive Science*, 17(1), 87–116.
- (1997). *Situated cognition*. Cambridge: Cambridge University Press.
- Clark, A. (1997). *Being there: Putting brain, body, and world together again*. Cambridge, MA: MIT Press.
- (1999). An embodied cognitive science? *Trends in Cognitive Sciences*, 3(9), 345–51.
- (2003). *Natural-born cyborgs*. Oxford: Oxford University Press.
- Dawson, M. R. W. (1998). *Understanding cognitive science*. Oxford: Blackwell.
- (2013). *Mind, body, world: Foundations of cognitive science*. Edmonton, AB: Athabasca University Press.
- Dawson, M. R. W., Dupuis, B., and Wilson, M. (2010). *From bricks to brains: The embodied cognitive science of LEGO robots*. Edmonton, AB: Athabasca University Press.
- Dourish, P. (2001). *Where the action is: The foundations of embodied interaction*. Cambridge, MA: MIT Press.
- Downing, H. A., and Jeanne, R. L. (1988). Nest construction by the paper wasp, *Polistes* – A test of stigmergy theory. *Animal Behaviour*, 36, 1729–39.
- Dunning, D. C., and Roeder, K. D. (1965). Moth sounds and insect-catching behavior of bats. *Science*, 147(3654), 173–74.
- Fenton, M. B., and Fullard, J. H. (1979). Influence of moth hearing on bat echolocation strategies. *Journal of Comparative Physiology*, 132(1), 77–86.
- Fong, T., Nourbakhsh, I., and Dautenhahn, K. (2003). A survey of socially interactive robots. *Robotics and Autonomous Systems*, 42(3–4), 143–66.
- Fullard, J. H., Simmons, J. A., and Saillant, P. A. (1994). Jamming bat echolocation: The dogbane tiger moth *Cycnia tenera* times it clicks to the terminal attack calls of the big brown bat *Eptesicus fuscus*. *Journal of Experimental Biology*, 194, 285–98.
- Gardner, H. (1984). *The mind's new science*. New York: Basic Books.
- Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston, MA: Houghton Mifflin.
- (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.
- Grassé, P. P. (1959). La reconstruction du nid et les coordinations interindividuelles chez *Bellicositermes natalensis* et *Cubitermes sp.* la théorie de la stigmergie: Essai d'interprétation du comportement des termites constructeurs. *Insectes Sociaux*, 6(1), 41–80.
- Grey Walter, W. (1963). *The living brain*. New York: W. W. Norton & Co.
- Griffin, D. R., Friend, J. H., and Webster, F. A. (1965). Target discrimination by echolocation of bats. *Journal of Experimental Zoology*, 158(2), 155–68.
- Griffin, D. R., Webster, F. A., and Michael, C. R. (1960). The echolocation of flying insects by bats. *Animal Behaviour*, 8, 141–54.
- Hayes, P. J., Ford, K. M., and Agnew, N. (1994). On babies and bathwater: A cautionary tale. *AI Magazine*, 15(4), 15–26.
- Helmholtz, H. (1868/1968). The recent progress of the theory of vision. In R. M. Warren and R. P. Warren (Eds.), *Helmholtz on perception: Its physiology and development* (pp. 61–136). New York: John Wiley & Sons.
- Holland, O., and Melhuish, C. (1999). Stigmergy, self-organization, and sorting in collective robotics. *Artificial Life*, 5, 173–202.
- Horiuchi, T. K. (2005). “Seeing” in the dark: Neuromorphic VLSI modeling of bat echolocation. *IEEE Signal Processing Magazine*, 22(5), 134–39.
- Hristov, N. I., and Conner, W. E. (2005). Sound strategy: Acoustic aposematism in the bat-tiger moth arms race. *Naturwissenschaften*, 92(4), 164–69.
- Hurley, S. (2001). Perception and action: Alternative views. *Synthese*, 129(1), 3–40.
- Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.

- Karsai, I. (1999). Decentralized control of construction behavior in paper wasps: An overview of the stigmergy approach. *Artificial Life*, 5, 117–36.
- Lawrence, B. D., and Simmons, J. A. (1982). Echolocation in bats: The external ear and perception of the vertical positions of targets. *Science*, 218(4571), 481–83.
- Marr, D. (1969). A theory of cerebellar cortex. *Journal of Physiology–London*, 202(2), 437–70.
- Miller, G. A., Galanter, E., and Pribram, K. H. (1960). *Plans and the structure of behavior*. New York: Henry Holt & Co.
- Moss, C. F., and Sinha, S. R. (2003). Neurobiology of echolocation in bats. *Current Opinion in Neurobiology*, 13(6), 751–58.
- Müller, R., Lu, H. W., and Buck, J. R. (2008). Sound-diffracting flap in the ear of a bat generates spatial information. *Physical Review Letters*, 100(10).
- Nelson, M. E., and MacIver, M. A. (2006). Sensory acquisition in active sensing systems. *Journal of Comparative Physiology A–Neuroethology Sensory Neural and Behavioral Physiology*, 192(6), 573–86.
- Newell, A. (1990). *Unified theories of cognition*. Cambridge, MA: Harvard University Press.
- Noë, A. (2002). Is the visual world a grand illusion? *Journal of Consciousness Studies*, 9(5–6), 1–12.
- (2004). *Action in perception*. Cambridge, MA: MIT Press.
- Norman, D. A. (1980). Twelve issues for cognitive science. *Cognitive Science*, 4, 1–32.
- (1998). *The invisible computer*. Cambridge, MA: MIT Press.
- (2002). *The design of everyday things* (1st Basic pbk. ed.). New York: Basic Books.
- Obrist, M. K., Fenton, M. B., Eger, J. L., and Schlegel, P. A. (1993). What ears do for bats: A comparative study of pinna sound pressure transformation in chiroptera. *Journal of Experimental Biology*, 180, 119–52.
- Pfeifer, R., and Scheier, C. (1999). *Understanding intelligence*. Cambridge, MA: MIT Press.
- Pylyshyn, Z. W. (2000). Situating vision in the world. *Trends in Cognitive Sciences*, 4(5), 197–207.
- (2003). *Seeing and visualizing: It's not what you think*. Cambridge, MA: MIT Press.
- Reijnen, J., Vanderelst, D., and Peremans, H. (2010). Morphology-induced information transfer in bat sonar. *Physical Review Letters*, 105(14).
- Rock, I. (1983). *The logic of perception*. Cambridge, MA: MIT Press.
- Roeder, K. D., and Treat, A. E. (1961). The detection and evasion of bats by moths. *American Scientist*, 49(2), 135–48.
- Roy, D. (2005). Grounding words in perception and action: computational insights. *Trends in Cognitive Sciences*, 9(8), 389–96.
- Rydell, J., Jones, G., and Waters, D. (1995). Echolocating bats and hearing moths: Who are the winners? *Oikos*, 73(3), 419–24.
- Schön, D. A. (1992). Designing as reflective conversation with the materials of a design situation. *Knowledge-Based Systems*, 5(1), 3–14.
- Scribner, S. (1985). Knowledge at work. *Anthropology and Education Quarterly*, 16(3), 199–206.
- Scribner, S., and Beach, K. (1993). An activity theory approach to memory. *Applied Cognitive Psychology*, 7(3), 185–90.
- Scribner, S., and Tobach, E. (1997). *Mind and social practice: Selected writings of Sylvia Scribner*. Cambridge: Cambridge University Press.
- Shapiro, L. A. (2011). *Embodied cognition*. New York: Routledge.
- Simon, H. A. (1969). *The sciences of the artificial*. Cambridge, MA: MIT Press.
- Susi, T., and Ziemke, T. (2001). Social cognition, artefacts, and stigmergy: A comparative analysis of theoretical frameworks for the understanding of artefact-mediated collaborative activity. *Journal of Cognitive Systems Research*, 2, 273–90.
- Theraulaz, G., and Bonabeau, E. (1999). A brief history of stigmergy. *Artificial Life*, 5, 97–116.
- Uexküll, J. von (2001). An introduction to Umwelt. *Semiotica*, 134(1–4), 107–10.
- Varela, F. J., Thompson, E., and Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.
- Vera, A. H., and Simon, H. A. (1993). Situated action: A symbolic interpretation. *Cognitive Science*, 17, 7–48.
- (1994). Reply to Touretzky and Pomerleau: Reconstructing physical symbol systems. *Cognitive Science*, 18, 355–60.
- Visser, W. (2006). *The cognitive artifacts of designing*. Mahwah, NJ: Lawrence Erlbaum Associates.
- von Frisch, K. (1974). *Animal architecture*. New York: Harcourt Brace Jovanovich.
- Wiener, N. (1948). *Cybernetics: Or control and communication in the animal and the machine*. Cambridge, MA: MIT Press.
- Winograd, T., and Flores, F. (1987). *Understanding computers and cognition*. New York: Addison-Wesley.

- Wotton, J. M., Haresign, T., and Simmons, J. A. (1995). Spatially dependent acoustic cues generated by the external ear of the big brown bat, *Eptesicus fuscus*. *Journal of the Acoustical Society of America*, 98(3), 1423–45.
- Wotton, J. M., and Simmons, J. A. (2000). Spectral cues and perception of the vertical position of targets by the big brown bat, *Eptesicus fuscus*. *Journal of the Acoustical Society of America*, 107(2), 1034–41.
- Zeng, J. Y., Xiang, N., Jiang, L., Jones, G., Zheng, Y. M., Liu, B. W., *et al.* (2011). Moth wing scales slightly increase the absorbance of bat echolocation calls. *PLoS One*, 6(11).

THE ENACTIVE APPROACH

Ezequiel Di Paolo and Evan Thompson

Embodied approaches to cognition hold that the body is crucial for cognition. Yet despite many decades of research,¹ what this “embodiment thesis”² (Wilson and Foglia, 2011) amounts to still remains unclear, as the present volume with its diverse range of contributions indicates (see also Shapiro, 2011). How to interpret the embodiment thesis depends on how to interpret the meanings of its key terms, “body” and “cognition,” as well as on what it means exactly to say that the body is “crucial” for cognition (Kyselo and Di Paolo, in press). In recent years, the term “embodied” has been used elastically to refer to anything from conservative ideas about how bodily action provides a format for neuronal representations (Goldman and de Vignemont, 2009; Gallese, 2010; Goldman, 2012) or helps to reduce computational load (Clark, 2008; Wheeler, 2005, 2010; Wilson, 2004), to a variety of “radical embodiment” (Clark, 1999; Thompson and Varela, 2001) proposals—for example, that kinesthetic body schemas are a constitutive part of mental skills (Lakoff and Johnson, 1999; Núñez, 2010), that sensorimotor know-how is a constitutive part of perceptual experience (O’Regan and Noë, 2001; Noë, 2004), that bodily life regulation is a constitutive part of phenomenal consciousness and its extended neurophysiological substrates (Thompson and Varela, 2001; Thompson and Cosmelli, 2011), and that social sensorimotor interaction can be a constitutive part of social cognition (De Jaegher, Di Paolo, and Gallagher, 2010). In some cases, these radical embodiment proposals are based on the “enactive” view that cognition depends constitutively on the living body, understood as an *autonomous* system (Varela, Thompson, and Rosch, 1991; Thompson, 2007; Di Paolo, 2009; Froese and Ziemke, 2009). Our aim in this chapter is to explain this key enactive notion of autonomy and why it is needed if embodied cognitive science is to offer a genuine alternative to more traditional functionalist and cognitivist views.

The body and autonomy

A key attribute of the living body is its individuation, the process by which it makes itself distinct from its immediate surroundings and that enables an observer to distinguish it as an identifiable entity. More precisely, a key attribute of the body is that it is *self-individuating*—it generates and maintains itself through constant structural and functional change. Yet many of the systems we study in science—particles, rivers, communities, galaxies, and even bodies—we typically individuate from the outside by convention, with varying degrees of accuracy. In other words, what

counts as one system versus another typically depends on the conventional criteria we use to individuate the system; such criteria include considerations of convenience, perceptual biases, longer versus shorter relative timescales of change, semi-arbitrary definitions, or historical or practical use. To this day, functionalism in cognitive science identifies cognitive systems in precisely this way, that is, by convention: a robot, a body, or an agent is specified as the system it is according to some tacit convention of perception, use, or measurement. Most embodied approaches to the mind also proceed in this way. Thus references to the “body” are understood contextually as references to a given anatomical structure or physiological function, to the details of a given sensorimotor system, or to being situated in a given world of habits, norms, skills, and so on. Yet, regardless of whatever conventional criteria we may use to individuate the body, the body—like all living systems—nonetheless possesses the peculiar attribute of being self-individuating, such that it actively generates and maintains the distinction between itself and its environment. A guiding idea of the enactive approach is that any adequate account of how the body can either be or instantiate a cognitive system must take account of this fact that the body is self-individuating.

This point brings us to the principal concept that differentiates enactivism from other embodied approaches to the mind—the concept of *autonomy*. By making use of this concept—which, as we will see, explains how bodies are self-individuating—we can give operational criteria for distinguishing cognitive systems from non-cognitive systems.

The idea of autonomy has roots in Maturana and Varela’s (1980) theory of autopoiesis. This theory has strongly influenced enactive thinking to the point that sometimes the style of enactivism based on the notion of autonomy has been branded “autopoietic enactivism” (Hutto and Myin, 2013). This easy label is descriptive but potentially misleading, for the key theoretical developments in this area concern various forms of extensions—perhaps even departures—from the original autopoietic framework (see Di Paolo, 2009; Thompson, 2011a, 2011b). These elaborations should become clear in this section for the case of autonomy (the same goes for other concepts in the enactive framework not discussed here in full, such as adaptivity, sense-making, and agency; see Di Paolo, 2005, 2009; Thompson, 2007, 2011a, 2011b).

Autonomy was initially conceived as a generalization of the concept of autopoiesis or self-production (Varela, 1979). The concept of autopoiesis describes a peculiar aspect of the organization of living organisms, namely that their ongoing processes of material and energetic exchanges with the world, and of internal transformation and metabolizing, relate to each other in such a way that the same organization is constantly regenerated by the activities of the processes themselves, despite whatever variations occur from case to case. Varela (1979) extended this idea into other domains. Thus, he identified a similar organizational logic in the animal nervous system and immune networks, and he hinted at the application of the concept of autonomy to other domains, such as communication networks and conversations.

An autonomous system is defined as an *operationally closed* and *precarious* system. Before unpacking these terms, it may help to look at the intuitive procedure that we can apply to tell whether or not we are observing an autonomous system.

Consider the following situation. A scientist is observing, recording, and intervening in various processes that she finds of interest. Either in the lab or in the field, she observes and measures variables and their relations, takes notes of events, and attempts to establish the connections between her observations. To a large extent, *what* she chooses to observe and record is a matter of choice, as are the procedures she follows. She may be interested in the fact that the temperature in the lab seems relatively constant throughout the day in spite of the varying temperatures outside. Or she may be looking at some chemical reactions and measuring the speed with which they happen. To keep to a general level, let us say that she is observing

processes. How each of these processes is identified is not important here; the means of identification will likely depend on the observer's history, skills, tools, and purposes.

As the scientist intervenes in the various processes she is observing, she takes note of regular effects on other processes. For example, she changes a setting in a thermostat and the room temperature is now maintained at a higher constant level. Or she observes that the chemical reactions are now happening at a higher rate, and so on. Eventually, she may be able to establish various relations between the observed processes. Some of these relations indicate merely contextual effects—the observed process is altered in some way by intervening on a different process; other relations are stronger and indicate enabling conditions—the observed process disappears or stops if a particular intervention is made on a different process (De Jaegher, Di Paolo, and Gallagher, 2010). Thus, modifying the thermostat setting brings the desired room temperature to a cooler or warmer value, but unplugging the air conditioning simply prevents any temperature regulation from happening at all. Temperature regulation as such has stopped as a process. Such enabling relations, of course, depend on the circumstances.

We can use Figure 7.1 to depict this kind of situation. The circles represent the processes being observed by the scientist. Whenever an enabling relation is established, the scientist draws

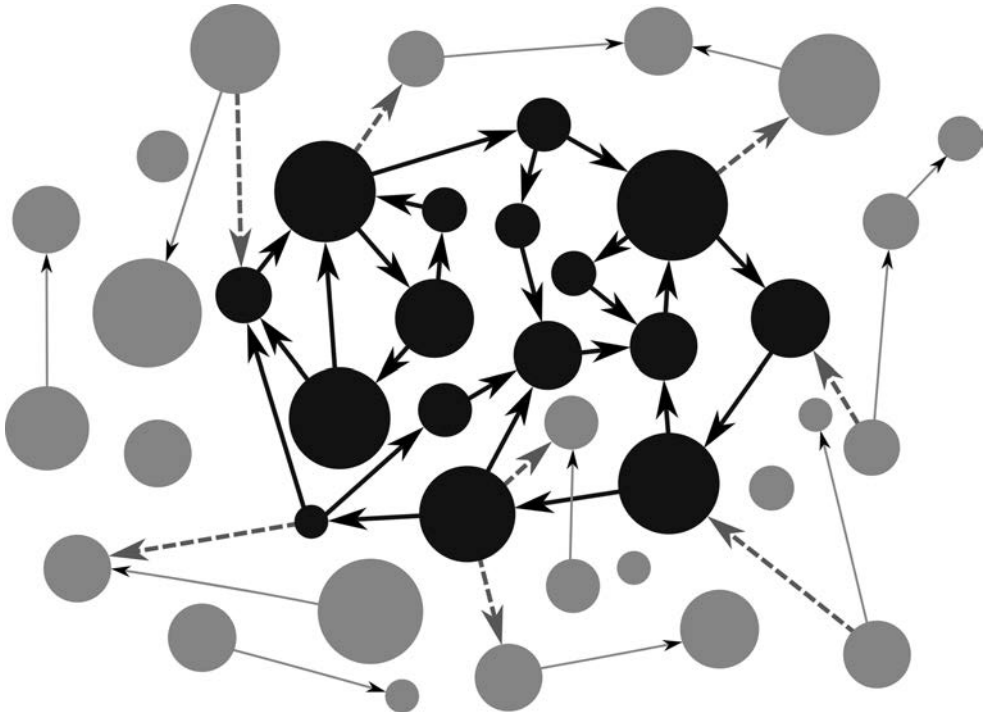


Figure 7.1 A schematic illustration of the concept of operational closure. Circles are observed processes and arrows indicate enabling conditions between processes. The black circles form part of an operationally closed network of enabling relations. Each black circle has at least one arrow arriving at it and at least one arrow coming from it respectively originating or terminating in another black circle. Dashed arrows indicate enabling relations between processes in the operationally closed network and processes that do not belong to it. (Copyright Ezequiel Di Paolo, 2013. This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 3.0 Unported License.)

an arrow going from the process that is perturbed to the process that stops or disappears as a consequence. An arrow going from process *A* to process *B* indicates that *A* is an enabling condition for *B* to occur. Of course, there may be several enabling conditions. We do not assume that the scientist is mapping all of them, only those that she finds relevant or can uncover with her methods.

As the mapping of enabling conditions proceeds, the scientist makes an interesting observation. There seems to be a set of processes that relate to each other with a special topological property. These processes are marked in black in the figure. If we look at any process in black, we observe that it has some enabling arrows *arriving at it* that originate in other processes in black, and moreover, that it has some enabling arrows *coming out of it* that end up also in other processes in black. When this condition is met, the black processes form a network of enabling relations; this network property is what we mean by *operational closure*.

Notice that this form of “closure” does not imply the independence of the network from other processes that are not part of it. First, there may be enabling dependencies on external processes that are not themselves enabled by the network; for example, plants can photosynthesize only in the presence of sunlight (an enabling condition), but the sun’s existence is independent of plant life on earth. Similarly, there may be processes that are made possible only by the activity of the network but that do not themselves “feed back” any enabling relations toward the network itself. Second, the arrows do not describe just any possible form of coupling between processes, but rather only a link of enabling dependence. Other links may exist too, such as interactions that have only contextual effects. In short, an operationally closed system should not be conceived as isolated from dependencies or from interactions.

Notice too that although the choice of processes under study is more or less arbitrary and subject to the observer’s history, goals, tools, and methods, the topological property unraveled is not arbitrary. The operationally closed network could be larger than originally thought, as new relations of enabling dependencies are discovered. But it is already an operationally closed network by itself and this fact cannot be changed short of its inner enabling conditions changing, that is, short of some of its inner processes stopping.

A living cell is an example of an operationally closed network. The closed dependencies between constituent chemical and physical processes in the cell are very complex, but it is relatively easy to see some of them. For example, the spatial enclosure provided by a semi-permeable cell membrane is an enabling condition for certain autocatalytic reactions to occur in the cell’s interior, otherwise the catalysts would diffuse in space and the reactions would occur at a much different rate or not at all. Hence there is an enabling arrow going from the spatial configuration of the membrane to the metabolic reactions. But the membrane containment is not a given; the membrane is also a precarious process that depends, among other things, on the repair components that are generated by the cell’s metabolism. So there is an enabling arrow coming back from metabolic reactions to the membrane. Hence we have already identified an operationally closed loop between these cellular processes. If the scientist chooses not to observe the membrane in relation to the metabolic reactions, she would probably miss the topological relation between them. Operational closure—cellular life in this case—can be missed if we choose to put the focus of observation elsewhere, but it is not an arbitrary property if we observe it at the right level.

Is autonomy the same as operational closure? Although it seems to have been the same for Varela (1979)—at least in terms of his formal definition of an autonomous system—we have argued in other writings that operational closure is not sufficient to capture certain important implications of the wider sense of the term “autonomy”—implications conveyed by notions such as “spontaneity,” “immanent purposiveness,” “intrinsic teleology,” and the “self-generation

of norms” (see Di Paolo, 2005; Thompson, 2007). Given the above definition of operational closure, various trivial examples of such closure may exist. For example, in cellular automata, the regeneration of an equilibrium state in each cell mutually depends on the equilibrium state in others, making the dependencies into a closed network.

We need an additional condition to make operational closure non-trivial, and this condition is that of *precariousness*. Of course, all material processes are precarious if we wait long enough. In the current context, however, what we mean by “precariousness” is the following condition: in the absence of the enabling relations established by the operationally closed network, a process belonging to the network will stop or run down.

It might seem at first that this condition is redundant. Why is precariousness not implied in the fact that a black circle in Figure 7.1 is always enabled by other black circles? So, surely if the enabling relations disappear, that process should stop. This stoppage would be the case if the scientist had exhaustively found all the enabling relations, but this need not be the case. There may also be redundancies among the enabling relations affecting a given process (more than one arrow may come into a circle, and this fact could mean either that all of the arrows are needed simultaneously or that different subsets of the incoming arrows are sufficient for the process to continue according to the conditions). An enabling relation, as we stated above, in principle holds only in given circumstances. When a process is enabled by the operationally closed network and by external processes as well, if the network is removed and the process remains—in the new circumstances—thanks only to the external support, then that process is not precarious. A precarious process is such that, whatever the complex configuration of enabling conditions, if the dependencies on other processes in the operationally closed network are removed, the process necessarily stops. In other words, it is not possible for a precarious process in an operationally closed network to exist on its own in the circumstances created by the absence of the network.

A precarious, operationally closed system is literally self-enabling, and thus it sustains itself in time partially due to the activity of its own constituent processes. Moreover, because these processes are precarious, the system is always decaying. The “natural tendency” for each constituent process is to stop, a fate the activity of the other processes prevents. The network is constructed on a double negation. The impermanence of each individual process tends to affect the network negatively if sustained unchecked for a sufficient time. It is only the effect of other processes that curb these negative tendencies. This dynamic contrasts with the way we typically conceive of organic processes as contributing positively to sustaining life; if any of these processes were to run unchecked, it would kill the organism. Thus, a precarious, operationally closed system is inherently restless, and in order to sustain itself despite its intrinsic tendencies towards internal imbalance, it requires energy, matter, and relations with the outside world. Hence, the system is not only self-enabling, but also shows spontaneity in its interactions due to a constitutive need to constantly “buy time” against the negative tendencies of its own parts.

The simultaneous requirement of operational closure and precariousness are the defining properties of autonomy for enactivism. It is this concept of autonomy that answers the opening question in this section about the individuation of the body. A body is understood as such an autonomous system, an understanding that allows for the possibility that any given body need not be constituted exclusively by its biochemical or physiological processes (Thompson and Stapleton, 2009; Kyselo and Di Paolo, in press).

Notice that what we have provided in this section is a clear, step-by-step procedure to answer empirically the question of whether a system is autonomous. The enactive concept of autonomy is entirely operational, and therefore naturalistic, though not reductionist. It is,

however, not a concept that could be captured using the methods of functionalism, and this point already entails a fundamental difference between enactive and functionalist approaches to the mind. As we have seen, autonomy requires precariousness, but precariousness is not a positive property of a process, but rather an unavoidable aspect of materiality. In the current context, precariousness is the insufficient permanence of any positive property that might play a positive functional role in sustaining the autonomous system in the absence of the system's closed organization. Precariousness cannot be "revealed" as a positive property and yet its negative effects are what the system is constantly acting against. For this reason, precariousness might be partially modeled in functionalistic terms, but never fully captured in those terms, as the conditions that satisfy any functional approximation (for instance, a decay function affecting various parameters) are in fact themselves precarious if the system is really autonomous.

In this way, the enactive concept of autonomy captures individuation as a non-arbitrary ongoing process as well as the spontaneity of living bodies. The concept also leads to various other developments, such as a naturalistic way to account for what Kant described as the intrinsic teleology or immanent purposiveness that appears to belong to living beings by virtue of being self-organizing (Weber and Varela, 2002; Thompson, 2007).

Linked to the notion of autonomy are two other key enactive notions, those of *adaptivity* and *sense-making* (Di Paolo, 2005, 2009; Thompson, 2011a, 2011b). "Adaptivity" refers to the ability of certain autonomous systems to regulate their operationally closed processes in relation to conditions registered as improving or deteriorating, viable or unviable (Di Paolo, 2005). This ability for adaptive regulation is inextricably linked to autonomy insofar as it happens with respect to the implications for the continuation of the system's autonomous identity. "Sense-making" describes behavior or conduct in relation to norms of interaction that the system itself brings forth on the basis of its adaptive autonomy. An adaptive autonomous system produces and sustains its own identity in precarious conditions, registered as better or worse, and thereby establishes a perspective from which interactions with the world acquire a normative status. Certain interactions facilitate autonomy and other interactions degrade it. In Merleau-Ponty's words: "each organism, in the presence of a given milieu, has its optimal conditions of activity and its proper manner of realizing equilibrium," and each organism "modifies its milieu according to the internal norms of its activity" (Merleau-Ponty, 1963, pp. 148, 154). For the enactive approach, a system is cognitive when its behavior is governed by the norm of the system's own continued existence and flourishing. Basic cognition, on this view, is not a matter of representing states of affairs but rather of establishing relevance through the need to maintain an identity that is constantly facing the possibility of disintegration. From this perspective, the body is not just the means but also an end of being a cognitive system. To put the point another way, basic cognition is more a matter of adaptive self-regulation in precarious conditions than abstract problem solving. The point here is not to deny that we can and do engage in high-level problem solving. Rather, it is to say that this kind of narrow cognition presupposes the broader and more basic cognition that we call sense-making.

Applications of enactive ideas

Modeling autonomy: bacterial chemotaxis

The definition of autonomy we have given in the previous section aims at providing a procedure through which the question of whether a specific system is autonomous or not can be settled. It should then be possible to construct models of autonomous systems that enable us to explore some of the implications of this concept.

We begin with a couple of clarifications. First, by a “model” we mean a formal or material system that instantiates some of the properties of an autonomous system that are relevant in a particular context. By its nature, a model is a simplification and not a realization of the system being modeled. In other words, a model of an autonomous system is not, in itself, an autonomous system, nor is it meant to be, in the same sense that a fluid dynamics model of a river is not a river. The second clarification concerns the question of whether, given some modeling techniques, it is possible to capture all aspects of autonomy. This is an open question, but we can at least say that given our comments on precariousness and the fact that precariousness cannot be captured as a positive function, it is not possible to model full autonomy in traditional computational terms, including dynamical systems models. It may be the case that a full model of autonomy requires a material system that exhibits the relations of precarious operational closure among the processes that are involved in that system. A computer does not typically work in this way. Nevertheless, in the context of the goal of a computational model, we may approximate with sufficient accuracy those aspects that are relevant to the question at hand. This way of proceeding is no different from other kinds of scientific models; such models have a limited range of validity outside of which the modeling assumptions fail.

Matthew Egbert and colleagues have explored a series of dynamical systems models of autonomy in the context of bacterial behavior (Egbert, Barandiaran, and Di Paolo, 2010). These models explore the relation between autonomy and sense-making in its most basic forms, and so can help fine-tune enactive theory (bacterial chemotaxis is a canonical example of sense-making, often used by Varela himself; see Varela *et al.*, 1991; Thompson, 2007, 2011c). Egbert and colleagues take note of an interesting situation in bacterial research. For decades, the chemotactic behavior of bacteria has been investigated as if it did not depend on their metabolic state. Whether bacteria are “hungry” or “satiated,” it is assumed that they will always follow a chemical gradient towards sources of nourishment. Evidence shows, however, that the assumption of metabolism independence often fails (Alexandre and Zhulin, 2001). For example, in some species non-metabolizable chemical analogues of metabolizable attractants are not themselves attractants (even though they excite chemical sensors in the same way). In addition, the inhibition of the metabolism of a chemical attractant completely stops chemotaxis to this attractant and only this attractant. Furthermore, the presence of another metabolizable chemical prevents chemotaxis to all attractants studied. In short, there seems to be a deep link between metabolism, the autonomous process of self-construction, and behavior—the regulation of interactions with the world—as expected from the relation between autonomy and sense-making proposed by enactivism. By modeling metabolism as a cycle of autocatalytic reactions far from thermodynamic equilibrium, thus capturing some aspects of precarious operational closure, and by modeling behavior regulation as modulated by metabolism, Egbert and colleagues have managed to replicate various empirically observed behaviors of bacteria. These behaviors are chemotaxis towards metabolic resources and away from metabolic inhibitors, inhibition of chemotaxis in the presence of abundant resources, cessation of chemotaxis to a resource due to inhibition of the metabolism of that resource, sensitivity to metabolic and behavioral history, and integration of simultaneous complex environmental “stimuli.” Various extensions of this model make it possible to explore the evolutionary implications of this basic link between life and mind proposed by enactivism (Egbert *et al.*, 2012; Egbert, 2013; Barandiaran and Egbert, 2014).

Participatory sense-making

Another area where enactive ideas are making an impact is intersubjectivity research. This area has been a concern of enactivism for some time (Thompson, 2001, 2007). As a result of De

Jaegher and Di Paolo's (2007) introduction of the concept of "participatory sense-making," enactivism has begun to ramify into fields as varied as animal social behavior, psychiatry and psychopathology, social neuroscience, dance, music, literature and education studies, and embodied linguistics (see De Jaegher, Di Paolo, and Gallagher, 2010).

The enactive account of intersubjectivity calls attention to participatory and non-individualistic processes, unlike traditional approaches where social understanding is reduced to the inferences or simulations a typically passive observer can make about the intentions of others based on their external behavior. Making explicit the domain of social interaction is to take a crucial step away from methodological individualism. For this step, De Jaegher and Di Paolo (2007) use the idea of autonomy, but now applied to the relational processes that often take place in the encounter of two or more people. Accordingly, sometimes these encounters take on a life of their own and the actions of the agents involved, or their intentions, do not fully determine the outcome of the encounter, which also depends on its own relational and dynamic constituent processes. In these cases, where relational patterns emerge as autonomous and the interactors themselves remain autonomous, we are in the presence of a social interaction, which can be defined formally (De Jaegher and Di Paolo 2007, p. 493). The processes involved are patterns of intercorporeal coordination at various levels—imitative gestures, regulation of personal distance, posture and orientation, attunement to conversation or walking rhythms, and so on (such patterns have long been investigated in psychology and social science).

Given that sense-making is an embodied process of active regulation of the coupling between agent and world, social interaction—through patterns of bodily coordination and breakdown—opens the possibility of this process being shared among the interactors. This shared form of sense-making is what is meant by "participatory sense-making." It happens to various degrees, from orientation of individual sense-making (someone draws our attention to an aspect of the world we have ignored) to joint sense-making (a piece of work is literally created together through a process that would not be possible by the individuals involved on their own).

This proposal has important empirical implications. For example, De Jaegher, Di Paolo, and Gallagher (2010) show that making the scientific study of interaction more explicit can offer new hypotheses about the processes sustaining a cognitive performance, and frees researchers from postulating complicated mechanisms in the individual brain that duplicate what the interactive dynamic configuration is able to bring about on its own. This proposal of paying more attention to interactive factors comes at a time when empirical methods in psychology and neuroscience (such as hyperscanning, thermal imaging, motion energy analysis, and second-person methodologies) have started to develop to the point that live and relatively unconstrained interactions can be directly investigated. These sciences may now move away from the traditional individualistic and observational paradigms. It is even possible to propose broad empirical hypotheses about the relation between individual brain mechanisms, the development of interactive skills, and interactive history (Di Paolo and De Jaegher, 2012).

Through participatory sense-making, the enactive approach thematizes pre-existing empirical and practical knowledge that has often been neglected by mainstream theoretical frameworks. Such thematization is particularly the case in psychiatry, where the social dimension of the etiology, diagnosis, and intervention for disorders such as schizophrenia or autism has been well known in practice and to a large extent well documented, and yet cognitivist or neurobiological approaches have tended to downplay this dimension. Explanations of mental disorders too can be reconsidered from a non-individualistic enactive perspective (e.g. de Haan and Fuchs, 2010; De Jaegher and Di Paolo, 2013). Such reconsideration does not imply positing either the individual or the interactive levels as fundamental, but rather understanding the mutually enabling relations between the two levels (Fuchs, 2012; De Jaegher and Di Paolo, 2013).

Conclusion

In conclusion, we can use the concepts sketched here to present brief enactive responses to the following three questions about the embodiment thesis that the body is crucial for cognition:

- (1) What is meant by *body*? (2) What is meant by *cognition*? (3) What is meant by *crucial*?
- (1) We have seen that enactivism, unlike other approaches, attempts to provide a principled definition of the body as a self-individuating system. The concept of autonomy is what allows us to provide this definition. Thus, what is meant by “body,” for the enactive approach, is not the body as a functional system defined in terms of inputs and outputs—as it is for functionalist cognitive science—but rather the body as an adaptively autonomous and therefore sense-making system.³
- (2) Cognition, in its most general form, is sense-making—the adaptive regulation of states and interactions by an agent with respect to the consequences for the agent’s own viability.
- (3) Without a body, there cannot be sense-making. Moreover, sense-making is a bodily process of adaptive self-regulation. The link between the body and cognition is accordingly constitutive and not merely causal. To be a sense-maker is, among other things, to be autonomous and precarious, that is, to be a body, in the precise sense of “body” that the enactive approach indicates.

Notes

- 1 Dreyfus (1972) is probably the earliest statement of what is now known as embodied cognitive science. Yet this work was largely critical. Constructive theories and models of embodied cognition started to arrive in the mid-1980s, in works by Winograd and Flores (1986), Lakoff (1987), and Johnson (1987).
- 2 Wilson and Foglia (2011, n.p.) state the embodiment thesis as follows: “Many features of cognition are embodied in that they are deeply dependent upon characteristics of the physical body of an agent, such that the agent’s beyond-the-brain body plays a significant causal role, or a physically constitutive role, in that agent’s cognitive processing.”
- 3 Note that the human body as a whole comprises a number of overlapping autonomous systems, such as the nervous system and the immune system, and that these systems can incorporate extra-organic elements (e.g. neural prosthetics) into their operationally closed networks of enabling processes (Di Paolo, 2009; Thompson and Stapleton, 2009). For discussion of the relation between these systemic characterizations of the body and the phenomenological or subjective and experiential aspects of the body, see Thompson 2007.

References

- Alexandre, G., and Zhulin, I. B. (2001). More than one way to sense chemicals. *Journal of Bacteriology*, 183, 4681–86.
- Barandiaran, X. E., and Egbert, M. D. (2014). Norm-establishing and norm-following in autonomous agency. *Artificial Life*, 20(1), 5–28. doi:10.1162/ARTL_a_00094
- Clark, A. (1999). An embodied cognitive science? *Trends in Cognitive Sciences*, 3, 345–51.
- (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*, New York: Oxford University Press.
- de Haan, S., and Fuchs, T. (2010). The ghost in the machine: Disembodiment in schizophrenia – Two case studies. *Psychopathology*, 43, 327–33.
- De Jaegher, H., and Di Paolo, E. (2007). Participatory sense-making: An enactive approach to social cognition. *Phenomenology and the Cognitive Sciences*, 6(4), 485–507.
- (2013). Enactivism is not interactionism. *Frontiers in Human Neuroscience*, 6(345).
- De Jaegher, H., Di Paolo, E., and Gallagher, S. (2010). Can social interaction constitute social cognition? *Trends in Cognitive Sciences*, 14(10), 441–47.

- Di Paolo, E. A. (2005). Autopoiesis, adaptivity, teleology, agency. *Phenomenology and the Cognitive Sciences*, 4, 97–125.
- Di Paolo, E. (2009). Extended life. *Topoi*, 28, 9–21.
- Di Paolo, E., and De Jaegher, H. (2012). The interactive brain hypothesis. *Frontiers in Human Neuroscience*, 6(163).
- Dreyfus, H. (1972). *What computers can't do*. New York: Harper & Row.
- Egbert, M. D. (2013). Bacterial chemotaxis: Introverted or extroverted? A comparison of the advantages and disadvantages of basic forms of metabolism-based and metabolism-independent behavior using a computational model,” *PLoS One*, 8(5), e63617.
- Egbert, M. D., Barandiaran, X. E., and Di Paolo, E. A. (2010). A minimal model of metabolism-based chemotaxis. *PLoS Computational Biology*, 6(12), e1001004.
- (2012). Behavioral metabolism: The adaptive and evolutionary potential of metabolism-based chemotaxis. *Artificial Life*, 18(1), 1–25.
- Froese, T., and Ziemke, T. (2009). Enactive artificial intelligence: Investigating the systemic organization of life and mind. *Artificial Intelligence*, 173(3–4), 466–500.
- Fuchs, T. (2012). Are mental illnesses diseases of the brain? In S. Choudhury and J. Slaby (Eds.), *Critical neuroscience: A handbook of the social and cultural contexts of neuroscience* (pp. 331–44). New York: Wiley-Blackwell.
- Gallese, V. (2010). Embodied simulation and its role in intersubjectivity. In T. Fuchs, H. C. Sattel, and P. Henningsen (Eds.), *The embodied self: Dimensions, coherence and disorders* (pp. 78–92). Stuttgart: Schattauer.
- Goldman, A. (2012). A moderate approach to embodied cognitive science. *Review of Philosophy and Psychology*, 3(1), 71–88.
- Goldman, A., and de Vignemont, F. (2009). Is social cognition embodied? *Trends in Cognitive Sciences*, 13(4), 154–59.
- Hutto, D., and Myin, E. (2013). *Radicalizing enactivism: Basic minds without content*. Cambridge, MA: MIT Press.
- Johnson, M. (1987). *The body in the mind: The bodily basis of meaning, imagination, and reason*. Chicago: University of Chicago Press.
- Kyselo, M., and Di Paolo, E. (in press). Locked-in syndrome: A challenge for embodied cognitive science. *Phenomenology and the Cognitive Sciences*. doi:10.1007/s11097-013-9344-9
- Lakoff, G. (1987). *Women, fire, and dangerous things: What categories reveal about the mind*. Chicago: University of Chicago Press.
- Lakoff, G., and Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to Western thought*. New York: Basic Books.
- Maturana, H., and Varela, F. (1980). *Autopoiesis and cognition: The realization of the living*. Dordrecht: D. Reidel Publishing Co.
- Merleau-Ponty, M. (1963). *The structure of behavior* (A. Fisher, Trans.). Pittsburgh, PA: Duquesne University Press.
- Noë, A. (2004). *Action in perception*. Cambridge, MA: MIT Press.
- Núñez, R. (2010). Enacting infinity: Bringing transfinite cardinals into being. In J. Stewart, O. Gappene, and E. Di Paolo (Eds.), *Enaction: Towards a new paradigm in cognitive science* (pp. 307–33). Cambridge, MA: MIT Press.
- O'Regan, K., and Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, 24, 939–1031.
- Shapiro, L. (2011). *Embodied cognition*. New York: Routledge.
- Thompson, E. (2001). Empathy and consciousness. *Journal of Consciousness Studies*, 8(5–7), 1–32.
- (2007). *Mind in life: Biology, phenomenology, and the sciences of mind*. Cambridge, MA: Harvard University Press.
- (2011a). Précis of *Mind in Life*, by E. Thompson. *Journal of Consciousness Studies*, 18, 10–22.
- (2011b). Reply to commentaries. *Journal of Consciousness Studies*, 18, 176–223.
- (2011c). Living ways of sense-making. *Philosophy Today* (SPEP Suppl.), 114–23.
- Thompson, E., and Cosmelli, D. (2011). Brain in a vat or body in a world? Brainbound versus enactive views of experience. *Philosophical Topics*, 39, 163–80.
- Thompson, E., and Stapleton, M. (2009). Making sense of sense-making: Reflections on enactive and extended mind theories. *Topoi*, 28, 23–30.
- Thompson, E., and Varela, F. (2001). Radical embodiment: Neural dynamics and consciousness. *Trends in Cognitive Sciences*, 5, 418–25.
- Varela, F. J. (1979). *Principles of biological autonomy*. New York: Elsevier; North Holland.

- Varela, F. J., Thompson, E., and Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.
- Weber, A., and Varela, F. J. (2002). "Life after Kant: Natural purposes and the autopoietic foundations of biological individuality." *Phenomenology and the Cognitive Sciences*, 1, 97–125.
- Wheeler, M. (2005). *Reconstructing the cognitive world: The next step*. Cambridge, MA: MIT Press.
- (2010). In defense of extended functionalism. In Richard Menary (Ed.), *The extended mind*. Cambridge, MA: MIT Press.
- Wilson, R. A. (2004). *Boundaries of the mind: The individual in the fragile sciences – Cognition*. Cambridge: Cambridge University Press.
- Wilson, R. A., and Foglia, L. (2011). Embodied cognition. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Fall 2011 ed.). Retrieved from <http://plato.stanford.edu/archives/fall2011/entries/embodied-cognition/>
- Winograd, T., and Flores, F. (1986). *Understanding computers and cognition: A new foundation for design*, Norwood, NJ: Ablex.

Further reading

The “enactive approach” to cognition was first proposed by Francisco Varela, Evan Thompson, and Eleanor Rosch, *The embodied mind: Cognitive science and Human experience* (Cambridge, MA: The MIT Press, 1991). The concept of “autonomy” (defined in terms of operational closure) was introduced by Francisco Varela, *Principles of biological autonomy* (New York: Elsevier North Holland, 1979). For an extensive contemporary statement of the enactive approach, covering many new developments in cognitive science, theoretical biology, and philosophy, see Evan Thompson, *Mind in life: Biology, phenomenology, and the sciences of mind* (Cambridge, MA: Harvard University Press, 2007), as well as the “*Précis of mind in life*,” together with “Commentaries” and the “Author’s reply,” published by the *Journal of Consciousness Studies*, 18 (2011). For the implications enactive approach for AI, see Tom Froese and Tom Ziemke, “Enactive artificial intelligence: Investigating the systemic organization of life and mind,” *Artificial Intelligence*, 173(3–4) (2009), 466–500. For elaboration of the concept of autonomy to include adaptivity and precariousness, see Ezequiel Di Paolo, “Autopoiesis, adaptivity, teleology, agency,” *Phenomenology and the Cognitive Sciences*, 4 (2005), 97–125. For the enactive approach to participatory sense-making and social cognition, see Hanne De Jaegher and Ezequiel Di Paolo, “Participatory sense-making: An enactive approach to social cognition,” *Phenomenology and the Cognitive Sciences*, 6(4) (2007), 485–507. For discussion of the relationship between the enactive approach and the extended mind or extended cognition theory, see Ezequiel Di Paolo, “Extended life,” *Topoi*, 28 (2009), 9–21, and Evan Thompson and Mog Stapleton, “Making sense of sense-making: Reflections on enactive and extended mind theories,” *Topoi*, 28 (2009), 23–30.

PART III

Applied embodied cognition

Perception, language, and reasoning

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8

MUSIC PERCEPTION AND EMBODIED MUSIC COGNITION

Marc Leman and Pieter-Jan Maes

Introduction

Music has the capacity to affect humans' affective, social and cognitive abilities in different ways. For example, music may be used to regulate a person's mood after a stressful day driving home. Music may be used to connect with other people during rituals, or dancing parties. And many people use music to enjoy the different flavors of sound in aesthetic experiences at home, to learn about the quality of organized sounds and interpret their meanings along with its flow. The different ways of interacting with music have in common that music is most engaging and thus attractive and alluring. People get involved with music and want to be fully absorbed by it. Apparently, there are few things in our environment that touch human nature so profoundly. Why is it? And what is the possible benefit of this musical power? These questions turn out to be extremely difficult and hard to answer because musical experience is subtle and ineffable. Moreover, there are many variable factors that play a role, such as the energetic level or mood of the subject involved with music, the previous preoccupations and conditioning, personality, familiarity, cultural background, context, or educational level. In short, the elusive character of music and the variable context in which music is dealt with make it a challenging research topic. Nevertheless, the power of music touches the core of our human abilities and its understanding necessitates an interdisciplinary research approach. As a matter of fact a core factor of musical power is based on the listener's ability to interact with music. And a major precondition of this ability is that music is perceived, that is, processed through the senses, perhaps on the basis of previous perception, perhaps involving awareness, conceptualization and interpretation. The concept of perception thus involves a range from sensation to cognition, emotion and even interpretation. In what follows we first consider music perception from a cognitive viewpoint. Then we provide a critique of this cognitive approach and we look for direct evidence for the hypothesis that music perception is integrated with other modalities of human behavior, such as movement and emotion. In the final section we present a dynamic framework in which music perception is tightly linked with body movement, action and environmental interaction.

Music perception and cognition

Research on music perception has been guided by a paradigm that focuses on the anticipation of perceived structural components in music (Meyer, 1956; Huron, 2006; Honing, 2011).

Anticipation is based on the ability to discern patterns (e.g. melodies, rhythms, timbres) that emerge from music through our senses. These patterns are compared with previously stored knowledge and used to generate expectations about music. The degree of match between the expected and the newly perceived pattern may then generate an outcome that is further processed by the emotional or motor system. Consider the perception of articulated tones generated on a piano. They generate harmonic, melodic and tonal expectations on top of a temporal structural grid, called meter. Depending on the tones played, the expectation may be strong or weak. For example, in a particular context of the C major key, the chord sequence D7-D7-Dmin7-G7 (one chord per bar) may generate a strong expectation for Cmaj7 on the next bar. Such chords, perhaps enforced by particular rhythms and turns of a melody played on top of them, allow the prediction in time of newly incoming articulated tones. Obviously, the degree of match between the expected tones and the new tones creates tensions and relaxations that may engage our affective and emotional engagement with music. In this case the sequence D7-D7-Dmin7 culminating to G7 creates tension, while the G7 going to Cmaj7 creates a relaxation. In short, perceptive processes evoke anticipations that lead to the emergence of tensions and relaxations, which ultimately lock into practices that give rise to signification, such as mood regulation, bonding and aesthetic experience.

Obviously, over centuries, theories have been developed that capture the essence of how this kind of anticipation works in practice, using a level of description that draws upon rules and attributed functions. In the above example, the D7 is recognized as having the function of a secondary dominant (containing the notes f#-c), which is first smoothed by the Dmin7 (containing the notes f-c) but then further prepared by the dominant G7 (notes f-b) to go to the notes (e-c) of the tonic Cmaj7 chord. The note sequences of f#-f#-f-f-e and the contrasting note sequence of c-a-c-b-c somehow contribute to the strong resolving effect. However, these theoretical descriptions draw upon an intuitive knowledge of tonal functions and therefore, they do not provide a compelling scientific explanation of why these functions work the way they do.

Research in music perception aims at understanding the above example in terms of principles that explain these functions. In addition, pitches, melodies, chords and tonal functions form but one aspect of a number of structural categories that can be identified. The above example also draws upon temporal regularities leading to the perception of meter, and the emergence of what is called “harmonic rhythm,” that is, the weight of the chords according to their position in the metric-structural grid. The tones are played with a particular timbre and so on. All of this is part of what could be called emergent patterns of our perception. They are patterns that move out of other patterns, yielding new patterns at higher experiential levels.

Obviously the paradigm of music perception has been strongly influenced by the idea that anticipation of emerging forms may be determined by previous exposure to the musical repertoire and thus by information that is stored in the long-term memory as a result of learning. In that sense we speak about music perception as a cognitive process. Clearly, if no long-term memory is involved, and the anticipation of emerging forms is purely based on acoustical structures, wired in auditory (physiological) principles, and a short-term memory that fades away after a few seconds, then music perception would not be linked with cognitive processes, but rather with sensory processes. The perception of pitch, for example, is known to be based on sensory mechanisms involving the analysis of frequencies (in the cochlear partition) and subsequent integration of the resolved components into the perceived pitch (in the inferior colliculus) (see e.g. Terhardt, Stoll, and Seewann, 1982; Langner, 1992). In contrast, the recognition of sequences from the *Sacre du printemps* by Igor Stravinsky is based on cognitive mechanisms because one has to know the piece in order to be able to recognize it. However,

the perception of a simple sequence of tones and chords, as given above, may be highly driven by the processing that occurs at the sensory level, and perhaps also factors that involve learning.

Moreover, music perception as a cognitive process can be described in terms of an abstract pattern-processing model that is independent from the physical carrier (body, hardware) of the processing. The processing consists of (1) a pattern-learning module that takes structures from music and organizes them into memory, (2) a pattern-prediction module that uses musical input and previously learned structures to predict the next input, (3) a pattern-association model that relates the consequences of the prediction to cognitive, emotive and motor outcomes. Levels (1) and (2) address syntactic processes, while level (3) addresses semantic processes.

A critique of music perception as cognition

In line with the cognitive approach, one could argue that the irresistible force of tonal sensitivity comes from the learning of co-occurrences of note sequences of the repertoire, independently from the acoustical and sensory processing. Just take a collection of music scores and count the frequency of the intervals in a context of preceding notes. This may already provide a good prediction model for music (Krumhansl, 1990). However, there is evidence that the compelling force of tonal sensitivity may emerge from the acoustical and sensory auditory constraints subsumed in this repertoire (Bidelman, 2013). The difference is big and the discussion is ongoing (Huron and Parncutt, 1993; Leman, 2000; Sethares, 2005; Plamondon, Milne, and Sethares, 2009; Marmel, Tillmann, and Delbé, 2010; Milne, Carlé, Sethares, Noll, and Holland, 2011; Rohrmeier and Koelsch, 2012). It is evident that the statistics of co-occurrences of tones in a repertoire may lead to accurate predictive models of tonal perception of that repertoire. However, the predictive model does not explain why the co-occurrences got into the repertoire. Indeed, if there is no compelling force in occurrences, why is the repertoire not just based on random co-occurrences? In contrast, sensory-based mechanisms offer an explanation on the basis of the acoustical structure of tones and the auditory mechanisms that process these structures (Bidelman, 2013). It seems that the human mind relies on both processing mechanisms, one that draws upon the inherent constraints provided by environment (acoustics) and body (auditory system), and another one that draws upon the regularities that can be picked up from the repertoire on top of this. In addition, it is likely that experts use acquired music theoretical knowledge to interpret, understand and reason about perceived tonal organizations (cf. the above example of the simple tonal sequence). Another example is concerned with the perception (and prediction) of musical tempo. There exist models for the prediction of meter (Large and Snyder, 2009). But how do we know what is fast or slow tempo of music? Some researchers may claim that the mind learns this from the statistics of tempi in the repertoire (showing a peak at about 2 hertz). However, again, these statistics do not explain the repertoire. Instead, an alternative explanation is that our reference point for fast or slow is just based on a biomechanical resonator in our human body, hence a reference outside the cognitive system, on which processing of meter perception would depend (Van Noorden and Moelants, 1999).

To sum up, the above examples show that some of the core cognitive phenomena associated with music perception require a foundation based on environmental constraints and particularities of the human body. Music perception, at levels that involve cognition, is not detached from the body or from the environment with which it interacts. At this point, it is important to state that there is little discussion about the fact that music perception involves the anticipation of emerging patterns. The question is more about the origins and the resources of anticipation, and to what degree that should be understood in relation to body and environment. Further

arguments in favor of embodiment are based on recent findings that show dependencies of music perception on movement and emotions.

Evidence for music perception as embodied cognition

Figure 8.1 shows a model in which perception of music is interconnected with other modules such as emotion and movement. Ultimately, this network may provide the basis for conceptualizations about music and for narrative accounts of musical aesthetics and experience (Barsalou, 2008). However, the link with conceptualization and language is not the focus of the present chapter. Starting from early work by Hevner (1935), there is a rich literature on how musical structural features can be correlated with affective and emotional appraisal, and arousal (Juslin and Sloboda, 2001; Sievers, Polansky, Casey, and Wheatley, 2013). In addition, recent work has focused on the link from perception to movement (Sievers *et al.*, 2013). Toiviainen, Luck, and Thompson (2010) show that periodicities on several metrical levels in music are simultaneously reflected in spontaneous music-induced movement. Naveda and Leman (2010) show that cognitive representations of music-dance interactions may rely on a sparse frame of reference points, suggesting that the metric structure of music is embodied in movements. However, one could argue that these findings are compatible with the idea that music processing is based on a disembodied cognitive processing, which then activates the motor system.

More direct evidence of embodied cognition is provided by studies showing how changes in the motor system correlate with changes in perception of structural and expressive features of music. Thereby, two categories of changes in the motor system are generally addressed: one category relates to impairments of the motor system (i.e. motor disorders), the other to the development of the sensorimotor system (i.e. sensorimotor learning).

(i) Concerning the effect of motor disorders on auditory perception, Pazzaglia and colleagues (Pazzaglia, Pizzamiglio, Pes, and Aglioti, 2008) claimed a causative link between auditory

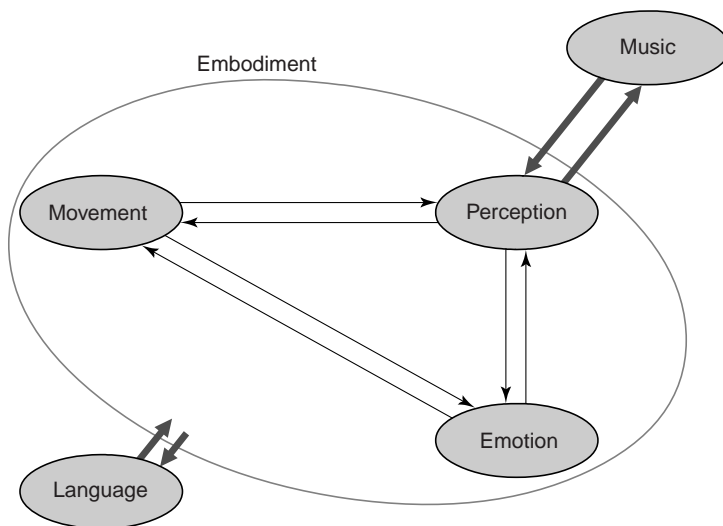


Figure 8.1 Music perception as embodied cognition. The model suggests interdependencies between perception, movement and emotion as part of an embodiment module that is connected with music and language.

recognition and the execution of actions. Working with apraxia patients, they showed how deficits in performing gestures are linked with the patients' ability to recognize these gestures by their mere sounds. In the study, patients were asked to listen to a sound and then choose from among four pictures the one corresponding to the heard sound. It was shown that limb and buccofacial apraxia patients are impaired in recognizing sounds linked to respectively limb and buccofacial human actions. Also, studies indicate that the processing and perception of musical features is impaired by motor dysfunctions. Grahn and Brett (2009) found that basal ganglia dysfunction in Parkinson's disease patients resulted in an impairment of the processing of rhythms that have a beat. Beste and colleagues (Beste, Schüttke, Pfeleiderer, and Saft, 2011) demonstrated similar effects of motor impairment on music processing in Huntington's disease patients. In this study, it was shown that, when listening to music, overall weaker activations occurred in brain areas that have been shown to be involved in auditory processing.

(ii) Sensorimotor learning relates to the acquisition of knowledge about the relationship between actions and sounds (Lalazar and Vaadia, 2008; Heyes, 2010; Cooper, Cook, Dickinson, and Heyes, 2012). By linking specific body movements to music, perception can be directed towards, or even impose, specific structures onto the music. Studies by Phillips-Silver and Trainor (2005, 2007) addressed the interaction between body movement and perception of musical rhythm. In an initial training phase, infants were passively bounced (Phillips-Silver and Trainor, 2005), or adults had to bounce actively by bending their knees (Phillips-Silver and Trainor, 2007) on every second versus every third beat of an ambiguous musical rhythm pattern. In a subsequent "test phase," infants' listening preferences were tested for two auditory versions of the rhythm pattern (duple and triple form) (Phillips-Silver and Trainor, 2005), or the adults were asked to listen to two auditory rhythms (duple and triple rhythm) and to select the one they thought matched what they heard during the training phase (Phillips-Silver and Trainor, 2007). The results showed that the preferences and interpretations were oriented toward the auditory stimulus that matched the metrical form of their movement training.

In another study (Sedlmeier, Weigelt, and Walther, 2011), it is shown that real or imagined body movements during music listening may co-determine music preferences. Sedlmeier *et al.* activated muscles whose innervations have been shown to be associated with positive and negative emotions. Accordingly, activation of the positively associated muscle groups led to higher preference ratings for the music pieces than activation of the negatively associated ones, suggesting that body movements, both real and imagined, may play an important role in the development of music preferences. Maes and Leman (2013) addressed the question whether expressive body movements can condition children's perception of musical expressiveness. They trained children with a happy or a sad choreography in response to music that had an expressively ambiguous character. Afterwards, the children's perception of musical expressiveness in terms of valence and arousal was assessed. The results suggested that the expressive qualities of the movements associated with the music had a significant impact on how children perceived musical expressiveness. In addition, several other studies indicate that performing body movements while listening to music increases people's sensitivity to better identify temporal structures in music (Su and Pöppel, 2012; Iordanescu, Grabowecky, and Suzuki, 2013; Manning and Schutz, 2013).

The above studies show that movements influence our perception of musical structure, affect and expression. Moreover, it is interesting to note that developments in technology-based applications in the field of music and dance education start to pick up these ideas (Maes, Amelynck, and Leman, 2012; Maes, Amelynck, Lesaffre, Arvind, and Leman, 2013).

In line with these previous findings, studies have shown that also the visual aspects of a music performer's body movements can alter observers' perceptual and aesthetic judgments of the

produced music. Thompson, Graham, and Russo (2005) showed that facial expressions and expressive hand gestures of music performers (i.e. vocal and guitar performance) can influence listeners' auditory perception of musical dissonance, melodic interval size, and affective valence. Similar findings are provided by Juchniewicz (2008), showing how the type of physical movement exhibited by a piano player while performing a musical excerpt (i.e. "no movement", "head and facial movement" and "full-body movement") alters listeners' judgments of the piano performance in terms of phrasing, dynamics, rubato and overall musical performance. These findings point out that crossmodal interactions between visual and auditory information exhibited in a music performance need to be taken into account for understanding people's overall engagement with music.

There is also evidence that emotional states influence memory and expression of perceived music, suggesting that music perception also depends on emotional states. For example, Houston and Haddock (2007) conditioned subjects with positive, negative or neutral mood. In a positive mood, melodies in major keys were better recognized than melodies in minor keys, whereas the reverse effect was seen for negative moods. Hunter, Schellenberg, and Griffith (2011) found that listeners in a sad mood fail to show the typical preference for happy-sounding music, and they perceive more sadness in music that is ambiguous with respect to mood. Van Dyck and colleagues (Van Dyck, Maes, Hargreaves, Lesaffre, and Leman, 2013) examined the effect of two basic emotions, happiness and sadness, on spontaneous dance movements. After inducing emotional states of either happiness or sadness, participants danced intuitively to an emotionally "neutral" piece of music, composed specifically for the experiment. Results revealed that in the happy condition, participants moved faster, and with more acceleration. In addition, they made more expanded and more impulsive movements than in the sad condition. These findings provide evidence of the effect of emotion induction on dance movement reflecting the perception of music.

To sum up, it is only recently that researchers started to collect direct empirical evidence in favor of an embodied approach to music perception. The recent results suggest that a new way of understanding music perception is based on our understanding of a dynamic action-perception system that is associated with sensing, movement, cognition and emotion. Basically this dynamic system determines complex meaning formation in relation to body and environment (Maes, Leman, Palmer, and Wanderley, 2014).

A dynamic framework for music perception based on embodied cognition

The above findings can be explained in terms of a bidirectional action-perception coupling. In one direction, incoming sensory information is transformed into corresponding motor representations on the basis of a direct-matching or mirroring (Rizzolatti, Fogassi, and Gallese, 2001). It explains why so many people tend to move along with the expressive patterns they hear in music. In the other direction, sensory outcomes are predicted based on planned or executed actions (Waszak, Cardoso-Leite, and Hughes, 2012). This explains why the perception of ambiguous musical patterns can be influenced by movements, as movements prompt people to impose – at least temporarily – certain anticipated structures (e.g. rhythm, melody, dynamics, phrasing, etc.) or affective qualities onto the music. The two directions are coupled in the sense that the mere activation of one representation (i.e. action or perception) results in the activation of the other. This provides a model that can explain, at least partly, how decoding and prediction of expressiveness and of structural features (e.g. pitch, rhythm, etc.) in music works, namely by association with expressive gestures. Accordingly, it provides a model for our understanding of

how music perception relates to goal-directed actions, namely by linking perceived patterns to actions that are associated with predicted outcomes and intended goals. Some further refinements of this theory are possible (Maes *et al.*, 2014). A first refinement relates to the nature of the representations. According to the common-coding theory (Prinz, 1997) the planning or executing of an action and the perception of the sensory outcome of this action lead to similar activation patterns in the brain involving sensory and motor-cortical areas. Important in this theory is that the integration of motor, sensory and introspective representations lead to internal models of the relationship between the body, the mind and the external environment. Also, in this theory, it is important to address how action-perception couplings can be developed through associative learning processes (Lalazar and Vaadia, 2008; Heyes, 2010; Cooper *et al.*, 2012). Through the repeated physical experience of specific actions in relation to specific sounds and introspective states, excitatory links are established between the involved motor, sensory and introspective representations in the brain. As these links have been shown to be important for the perception of music, it is important to better understand the processes underlying their formation. Rightfully, one could argue that the repeated experience of co-occurring sound patterns, actions and introspection lead to internal models that further regulate people's engagement with, and perception of, music. However, the statistics of co-occurrences do not explain why specific – and not just random – associations entered into the repertoire. The specification of co-occurrences is, at least partly, rooted into (i) the physical principles governing the transfer of energy of human motion into sound energy, (ii) cultural predispositions about the relationship between sound, action and introspection, and (iii) biological principles connecting specific acoustical characteristics of music to emotional responses (cf. brainstem reflexes; Juslin and Västfjäll, 2008). This interweaving of physical, cultural and biological predispositions, and as a consequence of learned and innate processes, must be taken into account to provide better insights into the human psychology of music. Another refinement that could be made concerns a distinction between action-perception loops and sensorimotor loops. The idea is that action-perception loops tap into a container of general expressive gestures whereas the sensorimotor loop allows the refinement of execution of the general expressive gestures in response to the environment. For example, while listening, the choreography of a dance pattern can be planned, but the fine details (e.g. hand movements) may be driven by a direct response to environmental circumstances.

Conclusion

The embodied music cognition paradigm changes our understanding of music perception in the sense that we consider music perception from the viewpoint of interaction rather than from the viewpoint of perception without action (Leman, 2008). There is now ample evidence that music perception is tightly integrated with other modalities such as sensing, moving, planning, and with the environment. Compared to the (disembodied) cognitive approach, prediction remains an essential aspect of what has to be explained and understood about music perception. However, the focus is less on representations of structure and more on representations of interactions that allow structures to be exploited in an expressive, empathic and gestural way. Consequently, the idea that the brain works as an auditory sponge in relation to music can no longer be maintained. Other modalities, not least the modalities that act in the environment, influence the sponge. Hence it is better to use the metaphor of a system whose representations are focused on interaction patterns that allow the effective prediction of multimodal pattern exchanges with the environment using internal sensing (proprioception, interoception). It is likely that this ability to predict is developed as a result of associative learning processes that connect sensory, motor and introspective states into an integrated network. The important point here is that (i) music

perception cannot be disconnected from the environment and the brain, that (ii) music perception forms part of an interactive (action-perception) system that is multimodal, and that (iii) the mechanisms behind music perception are the same for music performance (although the latter aspect falls outside the scope of the present chapter).

The challenge is to consider music perception as part of a larger framework that can be helpful in understanding the effects of musical power on our general well-being. When speaking about mood regulation or the motivation to move, we already imply the involvement of the emotional and motor systems and consider the possibility that music perception (including its power to anticipate and affect our experience) is multimodal, involving auditory, motor and emotional systems. In recent years, there is a growing awareness of the fact that the embodied viewpoint on music perception has an explanatory capacity that ranges beyond what (disembodied) cognitive approaches could achieve.

References

- Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, 59, 617–45.
- Beste, C., Schüttke, A., Pfeleiderer, B., and Saft, C. (2011). Music perception and movement deterioration in Huntington’s disease. *PLoS Currents*, 3(1253).
- Bidelman, G. M. (2013). The role of the auditory brainstem in processing musically relevant pitch. *Frontiers in Psychology*, 4(264), 1–13.
- Cooper, R. P., Cook, R., Dickinson, A., and Heyes, C. M. (2012). Associative (not Hebbian) learning and the mirror neuron system. *Neuroscience Letters*, 540, 28–36.
- Grahn, J. A., and Brett, M. (2009). Impairment of beat-based rhythm discrimination in Parkinson’s disease. *Cortex*, 45(1), 54–61.
- Hevner, K. (1935). Expression in music: A discussion of experimental studies and theories. *Psychological Review*, 42(2), 186–204.
- Heyes, C. (2010). Where do mirror neurons come from? *Neuroscience & Biobehavioral Reviews*, 34(4), 575–83.
- Honing, H. (2011). *Musical cognition: A science of listening*. Piscataway, NJ: Transaction Publishers.
- Houston, D., and Haddock, G. (2007). On auditing auditory information: The influence of mood on memory for music. *Psychology of Music*, 35(2), 201–12.
- Hunter, P. G., Schellenberg, E. G., and Griffith, A. T. (2011). Misery loves company: Mood-congruent emotional responding to music. *Emotion*, 11(5), 1068–72.
- Huron, D. B. (2006). *Sweet anticipation: Music and the psychology of expectation*. Cambridge, MA: MIT Press.
- Huron, D. B., and Parncutt, R. (1993). An improved model of tonality perception incorporating pitch salience and echoic memory. *Psychomusicology: Music, Mind and Brain*, 12(2), 154–71.
- Iordanescu, L., Grabowewy, M., and Suzuki, S. (2013). Action enhances auditory but not visual temporal sensitivity. *Psychonomic Bulletin & Review*, 20(1), 108–14.
- Juchniewicz, J. (2008). The influence of physical movement on the perception of musical performance. *Psychology of Music*, 36(4), 417–27.
- Juslin, P. N., and Sloboda, J. A. (2001). *Handbook of music and emotion: Theory, research, applications*. Oxford University Press, UK.
- Juslin, P. N., and Västfjäll, D. (2008). Emotional responses to music: The need to consider underlying mechanisms. *Behavioral and Brain Sciences*, 31(5), 559–75.
- Krumhansl, C. L. (1990). *Cognitive foundations of musical pitch*. New York: Oxford University Press.
- Lalazar, H., and Vaadia, E. (2008). Neural basis of sensorimotor learning: Modifying internal models. *Current Opinion in Neurobiology*, 18(6), 573–81.
- Langner, G. (1992). Periodicity coding in the auditory system. *Hearing Research*, 60(2), 115–42.
- Large, E. W., and Snyder, J. S. (2009). Pulse and meter as neural resonance. *Annals of the New York Academy of Sciences*, 1169(1), 46–57.
- Leman, M. (2000). An auditory model of the role of short-term memory in probe-tone ratings. *Music Perception*, 17(4), 481–509.
- (2008). *Embodied music cognition and mediation technology*. Cambridge, MA: MIT Press.
- Maes, P.-J., Amelynck, D., and Leman, M. (2012). Dance-the-Music: An educational platform for the modeling, recognition and audiovisual monitoring of dance steps using spatiotemporal motion templates. *EURASIP Journal on Advances in Signal Processing*, 2012(35), 1–16.

- Maes, P.-J., Amelynck, D., Lesaffre, M., Arvind, D. K., and Leman, M. (2013). The “Conducting Master”: An interactive, real-time gesture monitoring system based on spatiotemporal motion templates. *International Journal of Human-Computer Interaction*, 29, 471–87.
- Maes, P.-J., and Leman, M. (2013). The influence of body movements on children’s perception of music with an ambiguous expressive character. *PLoS One*, 8(1).
- Maes, P.-J., Leman, M., Palmer, C., and Wanderley, M. (2014). Action-based effects on music perception. *Frontiers in Psychology*, 4(1008), 1–14.
- Manning, F., and Schutz, M. (2013). “Moving to the beat” improves timing perception. *Psychonomic Bulletin & Review*, 20, 1133–39.
- Marmel, F., Tillmann, B., and Delbé, C. (2010). Priming in melody perception: Tracking down the strength of cognitive expectations. *Journal of Experimental Psychology: Human Perception and Performance*, 36(4), 1016–28.
- Meyer, L. B. (1956). *Emotion and meaning in music*. Chicago: University of Chicago Press.
- Milne, A. J., Carlé, M., Sethares, W. A., Noll, T., and Holland, S. (2011). Scratching the scale labyrinth. In C. Agon, M. Andreatta, G. Assayag, E. Amiot, J. Bresson, and J. Mandereau (Eds.), *Mathematics and Computation in Music (LNCs)* (Vol. 6726, pp. 180–95). Berlin: Springer.
- Naveda, L., and Leman, M. (2010). The spatiotemporal representation of dance and music gestures using Topological Gesture Analysis (TGA). *Music Perception*, 28(1), 93–111.
- Pazzaglia, M., Pizzamiglio, L., Pes, E., and Aglioti, S. M. (2008). The sound of actions in apraxia. *Current Biology*, 18(22), 1766–72.
- Phillips-Silver, J., and Trainor, L. J. (2005). Feeling the beat: Movement influences infant rhythm perception. *Science*, 308(5727), 1430.
- (2007). Hearing what the body feels: Auditory encoding and rhythmic movement. *Cognition*, 105, 533–46.
- Plamondon, J., Milne, A., and Sethares, W. A. (2009). Dynamic tonality: Extending the framework of tonality into the 21st century. Paper presented at the Annual Conference of the South Central Chapter of the College Music Society, Norman, OK.
- Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology*, 9(2), 129–54.
- Rizzolatti, G., Fogassi, L., and Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*, 2(9), 661–69.
- Rohrmeier, M. A., and Koelsch, S. (2012). Predictive information processing in music cognition: A critical review. *International Journal of Psychophysiology*, 83(2), 164–75.
- Sedlmeier, P., Weigelt, O., and Walther, E. (2011). Music is in the muscle: How embodied cognition may influence music preferences. *Music Perception*, 28(3), 297–306.
- Sethares, W. A. (2005). *Tuning, timbre, spectrum, scale*. New York: Springer.
- Sievers, B., Polansky, L., Casey, M., and Wheatley, T. (2013). Music and movement share a dynamic structure that supports universal expressions of emotion. *Proceedings of the National Academy of Sciences of the United States of America*, 110(1), 70–75.
- Su, Y. H., and Pöppel, E. (2012). Body movement enhances the extraction of temporal structures in auditory sequences. *Psychological Research*, 76(3), 373–82.
- Terhardt, E., Stoll, G., and Seewann, M. (1982). Pitch of complex signals according to virtual-pitch theory: Tests, examples, and predictions. *Journal of the Acoustical Society of America*, 71(3), 671–78.
- Thompson, W. F., Graham, P., and Russo, F. A. (2005). Seeing music performance: Visual influences on perception and experience. *Semiotica*, 156, 203–27.
- Toiviainen, P., Luck, G., and Thompson, M. R. (2010). Embodied meter: Hierarchical eigenmodes in music-induced movement. *Music Perception*, 28(1), 59–70.
- Van Dyck, E., Maes, P. J., Hargreaves, J., Lesaffre, M., and Leman, M. (2013). Expressing induced emotions through free dance movement. *Journal of Nonverbal Behavior*, 37(3), 175–90.
- Van Noorden, L., and Moelants, D. (1999). Resonance in the perception of musical pulse. *Journal of New Music Research*, 28(1), 43–66.
- Waszak, F., Cardoso-Leite, P., and Hughes, G. (2012). Action effect anticipation: Neurophysiological basis and functional consequences. *Neuroscience & Biobehavioral Reviews*, 36(2), 943–59.

9

ENACTIVE VISION

Erik Myin and Jan Degenaar

Enactivism and the sensorimotor account

Enactivism, ever since its first formulation by Varela, Thompson, and Rosch, has always laid great emphasis on organism/environment interactions as the proper framework for studying cognition. Minds have to be understood as “enacted” by situationally embedded living organisms.

By proposing this approach to minds, enactivists have explicitly opposed themselves to cognitivists, who take representation as their central posit (Varela, Thompson, and Rosch, 1991). Thus, it is claimed that cognition is, rather than representation of the world, “the enactment of a world and a mind on the basis of a history of the variety of actions that a being in the world performs” (Varela, Thompson, and Rosch, 1991, p. 9; see also Thompson, 2007). True to the enactivist motto that “a path is laid down in walking”; the role of internally stored rules and representations in accounting for cognition is thus replaced by an embodied history of interactions.

By taking up this position, enactivism reveals itself as committed to a strong notion of embodiment. Such a concept has to be distinguished from other senses of embodiment. One way to use “embodiment” is to emphasize the role of the particular properties of the body in shaping our cognitive capacities. Thus, to give a rather trite example, it could be argued that having ten fingers lies at the basis of the decimal system, so that even mathematics has a basis in the body. Such a use of the notion of embodiment is in no way incompatible with a traditional cognitive science approach, in which computations and internal representations are assigned a key role for explaining our cognitive capacities. In particular, one could conceive of the specifics of the body as constraining the form or content of our representations or computations.

In the sense of “embodied” at stake here, “embodied” is used in contrast with “representational,” such that saying that some capacity is embodied is to deny that it involves internal representations. One could argue, for example, that people embody the rules of their native language, in the sense that the rules are manifest, and only manifest in their utterances, or other practical dealings with language. The structure of language then is implicit in the practices; it is spread out in time, not represented anywhere. Of course, one could not embody rules without

having a body engaged in the relevant, rule-manifesting, activities, but the emphasis here lies not on the specifics of that body, but on what could be called the primacy of embodiment over representation. We will take enactivism as stating that cognition is embodied in this strong, or “radical” sense (Chemero, 2009; Hutto and Myin, 2013).

In the domain of perception, enactivism has become associated with the so-called sensorimotor contingency approach presented in O’Regan and Noë (2001). Vision, according to the sensorimotor approach “is something we do, rather than something that happens in us” (O’Regan and Noë, 2001). The approach rejects the view of vision as aimed at producing a “faithful metric-preserving replica of the outside world inside the head” (O’Regan, 1992). Instead, seeing is conceived of as an “exploratory activity,” “attuned to” sensorimotor contingencies, or ways in which sensory stimulation changes with movement—such as when a retinal image changes when one walks around an object. Seeing a scene or an object is, in the sensorimotor approach, comparable to feeling a surface or object, where the experience is of the whole surface or object, despite the fact that momentary tactile stimulation is limited to the fingertips making contact only at particular places.

Sensorimotor theorists have argued that the idea that vision should be understood as temporally extended interaction is supported by the insights it provides into the nature and character of perceptual experiences. According to the sensorimotor approach, perceptual experiences owe their identity to the patterns of sensorimotor contingencies typical of the kinds of organism/environment interactions those experiences normally arise in. For example, tactile feelings of hardness or softness are determined by particular patterns of experiences one has when engaging in such activities as squishing a sponge or pushing a brick wall. Similarly, that experiences of seeing differ as a class from experiences of hearing is due, according to the sensorimotor theory, to patterns of sensorimotor contingencies specific to vision and audition, such as that in seeing, but not in hearing, stimulation from a particular source stops when one turns one’s head sideways, or closes one’s eyes.

The crucial role played by patterns of sensorimotor contingency in shaping perceptual experience has been seen as supported by findings on adaptation to distorting or inverting glasses, as well as findings of experiments with sensory substitution devices (Hurley and Noë, 2003; Noë, 2004; O’Regan, 2011). For it seems that experiential change here follows on the heels of adaptation to patterns of sensorimotor contingencies.

The sensorimotor approach has been met with strong opposition and criticism, often formulated as criticism of enactivist approaches to perception generally (e.g. Block, 2005; Prinz, 2006, 2009). Critics of the sensorimotor approach have been puzzled, both by general claims about the role of sensorimotor contingencies in shaping experience and by the appeal to phenomena such as sensory substitution and distorted vision. Some critics have reached the verdict that these phenomena support the sensorimotor approach in no way whatsoever. They have further held that the sensorimotor claims regarding the determination of experiential quality fly in the face of the simplest observations about experience in imagery, dreaming or paralysis, in which experience seems radically disconnected from any presently obtaining patterns of sensorimotor interaction.

We will discuss the sensorimotor approach in the light of the broader enactivism as sketched above. We shall argue that spelling out the sensorimotor theory along enactivist lines, replacing representation by attunement due to a history of interactions, allows for a truly distinctive sensorimotor approach. This enactive sensorimotor approach is in perfect harmony with evidence about core phenomena such as vision with inverting glasses and sensory substitution. Moreover, an enactive sensorimotor approach allows for the accommodation of experiences such as in dreaming and perceptual imagery.

Enactive sensorimotor vision

Let us first return to the sensorimotor contingency account, as presented in O'Regan and Noë (2001). "Vision," it was said there, is "a mode of exploration of the world, mediated by knowledge of ... sensorimotor contingencies" (p. 940), the latter being characterized as "the *structure of the rules* governing the sensory changes produced by various motor actions" (p. 941). It was emphasized that the knowledge involved is "implicit," leading to a view of perception as a "skillful activity." The sensorimotor approach was presented as being opposed to approaches based on the assumption "that vision consists in the creation of an internal representation of the outside world whose activation somehow generates visual experience" (p. 940).

In order to get a firmer grip on the sensorimotor approach, it is helpful to look in some more detail at how the sensorimotor approach has been applied to a number of perceptual phenomena, in O'Regan and Noë (2001), and on later occasions (e.g. O'Regan, 2011).

As a first one of such, consider *expanded vision*. By "expanded vision" is meant the kind of visual experience as when standing in front of a scene and overseeing it, looking at a large screen, or holding a book opened in one's hand and having the experience of seeing both pages. Expanded vision is characterized by the experienced spatial and temporal continuity of what is seen. Essentially, seeing a scene is having the feeling of being in roughly simultaneous visual contact with a certain extent of the world.

Though expanded vision comes very naturally to us, certain by now well-known facts seem to stand in the way of a straightforward explanation of it. One relevant fact is that subjects are not continuously accessing the whole scene in the same high-quality way, due to such factors as differences in the spatial distribution of receptors in the retina, and the presence of the blind spot (O'Regan, 1992, 2011). The absence of homogeneous simultaneous access is further highlighted by results from studies on change blindness and inattention blindness, for they show that large changes in a scene can go unnoticed, for example when other changes are particularly conspicuous.

One way to explain expanded vision in the face of these facts is to relegate the homogeneity to something like the "internal representation of the outside world" (reiterating O'Regan and Noë, 2001). An inhomogeneous and gappy retinal image would be "filled in" to produce a homogeneous complete representation, to which or through which simultaneous access would still be possible.

The sensorimotor approach denies the need for such an inner simulacrum of temporal or spatial continuity. Instead it accounts for continuity in terms of sensorimotor regularities. One should not be misled by the fact of instantaneous access: perceivers have high-quality momentary access to only limited parts of the scene, while momentary access to other parts of the scene is of low quality. What is crucial, according to the sensorimotor approach, is that perceivers are set up to react to sudden changes in visual characteristics, so that, normally, any such significant change will not go unnoticed, but will lead the perceiver to focus on it. The trick to a successful change-blindness experiment is to tamper with this "grabiness" or "alerting capacity" (O'Regan, Myin, and Noë, 2005) of environmental changes, by introducing an even larger visual alteration such as a blank screen between two pictures of a scene before and after changes. Seeing the scene in an expanded way, then, is not the consequence of an expanded representation, but of one's capacity to interact with the scene.

Next, consider seeing an object. Sensorimotor theorists, following Donald MacKay, have compared the visual experience in object vision to the tactile experience of holding a bottle. The actual tactile contact with the bottle is only limited to where the fingers touch the bottle. Nevertheless, the experience is of a bottle, and not of disconnected bits of hard material. Again,

one could invoke a homogeneous representation to account for the experience of the whole object. Again the sensorimotor approach prefers an account in terms of being “attuned” to a sensorimotor pattern (O’Regan and Noë, 2001). The experience of feeling the whole bottle is then explained by the fact that one is attuned to the changes in stimulation that will occur when one makes certain movements. No representation needs to mediate, underlie or be causally involved in such a state of attunement. The same is claimed for seeing an object. To perceive a 3D object currently seen only from one side *as* a 3D object, one then does not need a representation: it suffices that one is attuned to the kinds of changes in stimulation that will result when either the object moves or when one moves with respect to it.

Thirdly, take seeing a color. It is a well-known fact, named “approximate color constancy,” that we more or less see the colors surfaces actually have, even if the stimulus that reaches the eye is a product of both the surface’s color and the contingent current illumination. Color experience is not a response to the local light as it currently reaches you; it is sensitive to a permanent surface property. A fundamental challenge for color science is to explain how this can happen. An enactive sensorimotor approach to color experience, in line with the accounts of expanded vision and object vision above, hooks on to the temporal extendedness of color perception (Brookes, 1992; Noë, 2004; O’Regan, 2011). The permanent property of color is identified with a *reflectance profile*: the way the surface reflects light under different lighting conditions. One can find out about the reflectance profile property by moving the colored object around or by observing surfaces under changing lighting conditions. Over time, one becomes sensitive to the underlying reflectance profile of a surface on the basis of minimal cues. Just as one can recognize a familiar person from a glimpse, one can recognize a reflectance profile on the basis of the behavior of the surface in a minimal set of lighting conditions. Such a minimal set, moreover, is almost always available, as it exists when different nearby objects reflect differently on a surface (Ruppertsberg and Bloj, 2007). In short, being capable of seeing colors then consists of being attuned to reflectance profiles, or to the changes in stimulation one would receive under various circumstances (see Philipona and O’Regan, 2006).

This way of looking at color illustrates the overall sensorimotor take on the qualitative character of perceptual experience. The sensorimotor approach claims that both the character of sensory qualities within a modality, such as the difference between softness and hardness, as well as differences between the character of modalities as a whole, are determined by differences in classes of sensorimotor contingencies typical of perceptual interactions. The experiential quality of softness differs from the quality of hardness, because of the different effects of pressing or squeezing. Similarly, touch differs from vision, among other things because tactile, but not visual, experience of an object comes to an end when immediate bodily contact is lost.

In the different cases of application of the sensorimotor approach surveyed in the above, the notion of “being attuned to sensorimotor contingencies” has played a prominent role. This raises questions about its precise meaning. What does it mean that a person is attuned to the sensorimotor contingencies of “red” or “softness”? A way of answering that question offered in O’Regan and Noë (2001) appeals to the exercise of the “mastery” or “knowledge” of sensorimotor contingencies, building on the already mentioned characterization of “vision as exploratory activity mediated by knowledge of sensorimotor contingencies.”

A problem with an appeal to knowledge is that it allows a representational interpretation, while the representationalist framework was resisted in the context of inner simulacra accounting for expanded vision. On such an interpretation, having knowledge about sensorimotor contingencies involves representing those sensorimotor contingencies. Perhaps the specification, in O’Regan and Noë (2001) and elsewhere, that the knowledge is meant to be “implicit,” is aimed at excluding such an interpretation in favor of an approach based on practical know-how,

or skills. However, as pointed out by Daniel Hutto, insisting that knowledge is meant to be “implicit” is not compatible with supposing that the knowledge plays a “mediating” role (Hutto, 2005). An appeal to mediating knowledge would imply commitment to an inter-mediating representational stage. Consistency with the initial non-representationalism of the sensorimotor approach can be regained by conceiving of “attunement to sensorimotor contingencies” as embodied in the strong sense mentioned at the beginning of this entry. Attunement to sensorimotor contingencies then means that an organism has acquired, on the basis of a history of interactions, a sensitivity in its perception and action for the ways stimuli change with movement.

In line with the strong notion of embodiment, the development of perceptual attunement is not conceived of in representationalist terms: the past is not playing its role in the present as represented past—as mediated by representations of the past. Enactivists relying on the strong notion of embodiment will insist that what a history of attunement has yielded is just that: attunement. Of course, attunement is attunement *to* certain external conditions. Call this the external aspect of attunement. Moreover, attunement is impossible without changed conditions in the organism. Call this the internal aspect of attunement. The mere existence of external and internal aspects of attunement do not necessitate representational descriptions, however. It is not because an organism has become attuned to certain circumstances that it *represents* those circumstances by some internal means. This is obvious in non-cognitive evolutionary adaptations: a bird’s wings partially constitute the bird’s internal conditions for moving appropriately in an aerial environment, but this does not imply that the bird or its wings represent these external conditions. Analogously, in the cognitive case, there is no logical need to describe the internal conditions that mediate cognitive attunements as representing the external circumstances of attunement.

The upshot is that, once the strong notion of embodiment is adhered to, a historical or developmental aspect comes to the fore, in a non-representationalist shape. Representationalists cannot deny a role for an organism’s history, but they may insist that an occurrent representation of the past needs to stand in for the real past, if the past is to yield an influence now. An enactive sensorimotor approach—that is, one defining attunement in the strong sense of embodiment—denies that the changes laid down in an organism’s history need to be representational. Without being representational, these changes can still retain their causal powers and allow for a bridge between the past and the present.

The enactive sensorimotor approach thus has the advantage of offering a reading of “attunement to sensorimotor contingencies” which is consistent with the anti-representationalism present in the sensorimotor analysis of expanded vision, object vision and the experience of properties such as softness or color.

Attunement in action

How does the enactive sensorimotor position relate to evidence to which sensorimotor theorists have appealed, in particular findings about adaptation to distorting glasses or about sensory substitution? Critics of the sensorimotor approach to perception and perceptual awareness have challenged it on this front, claiming that neither findings about distorting glasses nor those about sensory substitution confirm the sensorimotor approach (Block, 2005; Prinz, 2006; Klein, 2007).

By means of lenses or prisms, the light entering the eyes can be inverted in a left-right and/or an above-below dimension. This introduces systematic changes in the perceiver’s visual sensorimotor interaction with the environment. It has been reported that after extensive wearing of inverting glasses (within 6–10 days), visual abilities can be reacquired and one may once again

learn to see where things are (e.g. Stratton 1896, 1897; Taylor, 1962; Kohler, 1964; Dolezal, 1982; but see for example Linden, Kallenbach, Heinecke, Singer, and Goebel, 1999, for negative findings).

A phenomenon consistently reported throughout the literature is that, on first wearing inverting glasses, the stability of visual experience breaks down with head movements, as if the scene moves in front of one's eyes. This confirms that visual experience depends on sensorimotor contingencies, or on the relation between sensory stimulation and bodily movement (Taylor, 1962), and not on sensory stimulation alone. For since sensory stimulation is only spatially inverted, dependence on sensory stimulation only predicts inverted, but not unstable experience. Over the days, free-moving subjects adapt to the new situation and movement of the head no longer disrupts visual stability. The subject has become attuned to the novel sensorimotor contingencies, so that environmental movements lead to a distinctively visual experience of movement of the scene, while movement of the perceiver's own point or direction of view does not.

The crucial role of sensorimotor contingencies is further evidenced by the finding that, when studies use a chin rest to avoid head movement, adaptation is very restricted. Indeed, it seems that only adaptation of proprioceptive experiences—and no adaptation of visual experience—takes place in studies in which subjects perform actions when head movements are thus avoided (for some examples see Harris, 1965). We can make sense of this by distinguishing kinds of sensorimotor contingency, such as those related to *exploratory* activities such as looking from *performatory* activities such as grasping (Gibson, 1964): genuinely visual adaptation to wearing inverting glasses depends strongly on active visual exploration.

It is also clear that the distortion brought about by glasses affects different kinds of sensorimotor contingencies differently. Since the early reports of Stratton (1896, 1897), the focus of analysis in inversion studies has often been on the altered relation between vision on the one hand, and touch or bodily experiences on the other. However, inverting glasses introduce a conflict within spatial vision itself (Degenaar, in press). Head movements and eye movements involve different patterns of sensorimotor contingencies, some of which are changed and some of which remain unaffected under the distortion. A subject wearing the glasses has to adapt to the altered patterns, while leaving the existing attunement to the unaltered patterns intact.

Instead of leading to a prediction of a complete “inversion of experience” (Klein, 2007), a sensorimotor position thus leads to the expectation that experience, while certainly changing in systematic ways, will also retain continuities with experience before the goggles were put on. Sensorimotor theorists have emphasized that the sensorimotor view of vision as a set of sensorimotor capacities naturally allows for partial adaptation, and have pointed to such observations as that wearers of distorting goggles might have learned to see the positions of moving cars correctly, while still seeing the license plates as in a mirror (O'Regan and Noë, 2001; O'Regan, 2011).

Partial adaptation challenges the idea that vision is based on a unitary image or representation in the brain. It is thinking of vision in this distinctively non-sensorimotor way which leads to an expectation of “re-inversion” of experience. The contrast between this way of thinking and a sensorimotor approach becomes even stronger when the latter is of the enactivist variety, for an enactivist sensorimotor approach is more fully, or at least more explicitly, non-representational.

Sensory substitution devices enable a new mode of interaction with the environment, for example by transforming an image recorded by a camera into a pattern of tactile stimulation on the subject's skin (e.g. Bach-y-Rita, 1984) or into a pattern of auditory stimulation (e.g. Auvray, Hanne-ton, Lenay, and O'Regan, 2005; Auvray, Hanne-ton, and O'Regan, 2007). It has been found that after practice with such tactile-to-visual or tactile-to-auditory substitution devices, in

some cases blind or blindfolded subjects report the experience of objects in distal space, and describe vision-like experiences such as that objects increase in apparent size on approach. Following a training period, persons using a sensory substitution device have been found to acquire such capacities as involved in locomotor guidance, object localization, and object categorization (see Auvray and Myin, 2009, for further information and pointers to the literature).

As in the adaptation to inverting glasses, active exploration is required here: subjects must be able to control the camera in order to develop this kind of spatial experience (Bach-y-Rita, 1984; Auvray *et al.*, 2005). Sensorimotor theorists have referred to this adaptation as evidence for the approach, because it shows the pivotal role of sensorimotor contingencies in visual behavior and attunement. If a set of sensorimotor contingencies—such as those concerning change in size upon approach or retreat—are transferred from vision to touch then they seem to enable vision-like behavior and experience once the subject is attuned to the contingencies.

It is this positive point which is key: that, despite the novel modality these contingencies become embedded in, strikingly, they are able to entrain behavioral and experiential change. Critics of the sensorimotor approach have always been keen to point out that many, or at least some, aspects of experience remain linked to the modality the sensorimotor patterns are transferred to (e.g. Block, 2005; Prinz, 2006, 2009). Such an objection to the sensorimotor approach disregards the fact that the approach, just as was the case for inverting glasses, predicts a mixture of continuity and change in experience after one's having learned to perceive with a sensory substitution device. Sensory substitution devices add to the sensorimotor repertoire of the stimulated sense, without destroying the repertoire already present. Existing functionality—existing attunement to sensorimotor contingencies—remains in place. To the extent that aspects of the experiential character remain those of the “old” modality, this can be explained by the persistent attunement to the “old” sensorimotor contingencies. In other words, the sensory modality onto which the device is grafted, can show a level of “tenacity” (Myin, Cooke, and Zahidi, *in press*), or a lack of deference to the new sensorimotor context (Hurley and Noë, 2003).

Derivative experience

This nuanced sensorimotor perspective on inverting glasses and sensory substitution exemplifies how experience, at any moment, is a product of both the current stimulation and currently obtaining sensorimotor contingencies, *and* attunement due to a history of interactions. This basic tenet of the sensorimotor position allows it to meet an often formulated complaint that the sensorimotor approach cannot account for perceptual or perceptual-like experience under circumstances in which occurrent sensorimotor interactions differ from those characteristic of the experience. The range of cases invoked by critics includes dreaming, visual imagery and the perceptual experiences of paralyzed people.

Invoking these as counter-examples to the sensorimotor approach neglects the explanatory role played by the history of interactions. An appeal to this history of interactions, and the process of attunement it entrains, is essential in the sensorimotor account of all forms of perception. The fact that one feels the whole bottle on the basis of minimal sensory contact transcends one's currently occurring sensory stimulation precisely because of one's previous exposure to the sensorimotor contingencies of touching and exploring bottles. Because of this history, one is familiar with, or attuned to, a general pattern of sensorimotor contingencies typical of bottles, characterized by such regularities as that one will encounter more hard stuff when one slides one's fingers to either side. Dreaming, visual imagery and experience in paralysis, then, are cases in which the explanatory balance tips more fully in the direction of past

sensorimotor contingencies. What one experiences under such circumstances is dictated almost exclusively by one's attunement to previous interactive regularities, rather than by one's current stimulation. In the sense in which the character of experience in such circumstances is due to past, rather than to current, interactions, such experience is derivative. The derivative status of experiences in dreaming, imagery or paralysis, far from revealing them as being distant from sensorimotor interactions, in fact shows them to be deeply entrenched in them.

Conclusion

An enactive sensorimotor account can answer common criticisms, and it has been shown, for example by the investigations of Philipona and O'Regan (2006) on color, that the approach offers rich prospects for empirical expansion. Of course, there is need for further clarification and elaboration of the theoretical basis of the approach. Relevant steps are taken for example in the work of Buhrmann, Di Paolo, and Barandiaran (2013) on the key concept of sensorimotor contingencies. The above makes clear that the sensorimotor approach, spelled out fully along enactivist lines, offers a strong, substantive and fruitful perspective on perception, for vision as well as for other modalities.

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References

- Auvray, M., Hanne-ton, S., Lenay, C., and O'Regan, J. K. (2005). There is something out there: Distal attribution in sensory substitution, twenty years later. *Journal of Integrative Neuroscience*, 4(4), 505–21.
- Auvray, M., Hanne-ton, S., and O'Regan, J. K. (2007). Learning to perceive with a visuo-auditory substitution system: Localisation and object recognition with "The vOICe". *Perception*, 36, 416–30.
- Auvray, M., and Myin, E. (2009). From sensory substitution to sensorimotor extension. *Cognitive Science*, 33(7), 1036–58.
- Bach-y-Rita, P. (1984). The relationship between motor processes and cognition in tactile vision substitution. In W. Prinz and A. F. Sanders (Eds.), *Cognition and motor processes* (pp. 149–60). Berlin: Springer.
- Block, N. (2005). Review of the book *Action in perception*, by Alva Noë. *Journal of Philosophy*, 102, 259–72.
- Broackes, J. (1992). The autonomy of colour. In D. Charles and K. Lennon (Eds.), *Reduction, explanation, and realism* (pp. 421–65). Oxford: Clarendon Press.
- Buhrmann, T., Di Paolo, E., and Barandiaran, X. (2013). A dynamical systems account of sensorimotor contingencies. *Frontiers in Psychology*, 4(285).
- Chemero, A. (2009). *Radical embodied cognitive science*. Cambridge, MA: MIT Press.
- Degenaar, J. (in press). Through the inverting glass: First-person observations on spatial vision and imagery. *Phenomenology and the Cognitive Sciences*.
- Dolezal, H. (1982). *Living in a world transformed: Perceptual and performatory adaptation to visual distortion*, New York: Academic Press.
- Gibson, J. J. (1964). Introduction. *Psychological Issues*, 3(4), 5–13.
- Harris, C. S. (1965). Perceptual adaptation to inverted, reversed, and displaced vision. *Psychological Review*, 72(6), 419–44.
- Hurley, S. L., and Noë, A. (2003). Neural plasticity and consciousness. *Biology and Philosophy*, 18, 131–68.

- Hutto, D. D. (2005). Knowing what? Radical versus conservative enactivism. *Phenomenology and the Cognitive Sciences*, 4, 389–405.
- Hutto, D. D., and Myin, E. (2013). *Radicalizing enactivism: Basic minds without content*. Cambridge, MA: MIT Press.
- Klein, C. (2007). Kicking the Kohler habit. *Philosophical Psychology*, 20(5), 609–19.
- Kohler, I. (1964). The formation and transformation of the perceptual world. *Psychological Issues*, 3(4), 19–173.
- Linden, D. E. J., Kallenbach, U., Heinecke, A., Singer, W., and Goebel, R. (1999). The myth of upright vision: A psychophysical and functional imaging study of adaptation to inverting spectacles. *Perception*, 28, 469–81.
- Myin, E., Cooke, E., and Zahidi, K. (in press). Morphing senses. In M. Matthen, D. Stokes, and S. Biggs (Eds.), *Perception and its modalities*. New York: Oxford University Press.
- Noë, A. (2004). *Action in perception*. Cambridge, MA: MIT Press.
- O'Regan, J. K. (1992). Solving the “real” mysteries of visual perception: The world as an outside memory. *Canadian Journal of Psychology*, 46(3), 461–88.
- (2011). *Why red doesn't sound like a bell: Understanding the feel of consciousness*. New York: Oxford University Press.
- O'Regan, J. K., Myin, E., and Noë, A. (2005). Sensory consciousness explained (better) in terms of “corporality” and “alerting capacity.” *Phenomenology and the Cognitive Sciences*, 44, 369–87.
- O'Regan, J. K., and Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, 24, 939–73.
- Philipona, D. L., and O'Regan, J. K. (2006). Color naming, unique hues, and hue cancellation predicted from singularities in reflection properties. *Visual Neuroscience*, 23, 331–39.
- Prinz, J. (2006). Putting the brakes on enactive perception. *Psyche*, 12(1). Retrieved from <http://psyche.cs.monash.edu.au/>
- (2009). Is consciousness embodied? In P. Robbins and M. Aydede (Eds.), *Cambridge handbook of situated cognition* (pp. 419–36). Cambridge: Cambridge University Press.
- Ruppertsberg, A. I., and Bloj, M. (2007). Reflecting on a room of one reflectance. *Journal of Vision*, 7(13), 12.1–13.
- Stratton, G. M. (1896). Some preliminary experiments on vision without inversion of the retinal image. *Psychological Review*, 3, 611–17.
- (1897). Vision without inversion of the retinal image. *Psychological Review*, 4, 341–60 and 463–81.
- Taylor, J. G. (1962). *The behavioral basis of perception*. New Haven, CT: Yale University Press.
- Thompson, E. (2007). *Mind in life: Biology, phenomenology, and the sciences of mind*. Cambridge, MA: Harvard University Press.
- Varela, F. J., Thompson, E., and Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT Press.

Further reading

The sensorimotor approach to perception has been developed in somewhat different directions by Kevin O'Regan and Alva Noë—for example in the recent books, *Why red doesn't sound like a bell: Understanding the feel of consciousness* (New York: Oxford University Press, 2011), by Kevin O'Regan, and *Out of our heads: Why you are not your brain, and other lessons from the biology of consciousness* (New York: Hill & Wang, 2009), by Alva Noë. Among other divergences, O'Regan's book offers more links to empirical research, while Noë's book tries to advance a case for the idea that consciousness is not confined to the brain. Evan Thompson's *Mind in life: Biology, phenomenology, and the sciences of mind* (Cambridge, MA: Harvard University Press, 2007), has a chapter in which Thompson, one of the founders of enactivism, offers a sympathetic, but critical assessment of sensorimotor enactivism. Finally, Daniel Hutto and Erik Myin's *Radicalizing enactivism: Basic minds without content* (Cambridge, MA: MIT Press, 2013), presents arguments for construing enactivism and the sensorimotor approach in a radical, representation- or content-eschewing, way.

10

PERCEPTION AND/FOR/WITH/ AS ACTION

Cedar Riener and Jeanine Stefanucci

Perception-action

What is the nature of the relationship between perception and action? This is an enduring question in psychology which still does not have a definitive answer. Does perception *serve* action? Can actions occur *without* perception? In other words, are their underlying processes shared? Some have argued that perceptual processes are impenetrable and may operate outside of cognitive and motor processes (Pylyshyn, 1999). Others believe that perception and action are intimately linked and do not operate on their own (cf. Gibson). The question of whether and how perception and action are represented in the brain has also been central to debates about their relationship. Finally, questions of purpose in psychology inevitably include theories about the connection between perception and action.

In the following review, we summarize several approaches for understanding perception and action by considering the words that could connect “perception” to “action.” The categorical boundaries implied by “and,” “for,” “with,” and “as” are surely not definitive, and some approaches could fit into several of these categories. However, we believe that describing the nature of the relationship between perception and action with these categories is a good way of summarizing the different approaches used to study perception and action. Moreover, we discuss how these categories may also relate to the arguments about how perception and action are represented (or not) for each of these approaches. If readers are interested in neurobiological evidence for relationships between perception and action we point them to other reviews. For example, Creem-Regehr and Kunz (2010) include neurobiological as well as behavioral evidence in their review, and Norman (2002) attempts to reconcile some of the approaches by proposing that they reside in different neurological pathways (such as the two visual streams approach discussed below; Milner and Goodale, 2008). In this review, we will cover different approaches to perception and action using behavioral evidence, and propose that these approaches may overlap, but not entirely. We also focus our review on the nature of the relationship between perception and action in the context of space perception, whereas the other reviews are broader in scope.

We begin with perception AND action, which may seem to be a neutral default, but as we shall see, an even pairing is in itself a claim about the nature of their connection. After briefly exploring this approach, we follow with perception FOR action, which suggests that action is

the primary constraint on perception, as if the goal of perception is to enable effective action. Then we explore approaches which posit a more equal footing, in which perception exists in a constant dynamic feedback loop WITH action. Finally, we describe approaches that conceptualize most boundaries between the functions of perception and action as semantic. In these cases, perception is seen AS a type of action.

Perception AND action

Perception AND action implies that perception and action are separable, distinct functions. This approach is best represented by the information-processing approach described by Marr (1982), in which stages of visual processing gradually take raw stimulus features and combine them to pass them on to later stages such as action and decisions. Pylyshyn (1999) expanded on Marr, claiming that vision is “cognitively impenetrable.” In other words, early stages of vision are entirely separate and distinct from functions which receive information (“outputs”) or visual representations. According to this view, perception is unitary and distinct, and its outputs are unaffected by the processes receiving them (such as action or cognition).

For this view, perception is not embodied, but separate from the body, in which case researchers can study perception without considering the body and action. While early vision is described as cognitively impenetrable, it is also implied that actions (other than head movement) do not meaningfully affect early vision. One can thereby study vision and action separately. Since this is not an embodied view, but quite often a disembodied view of perception, an extensive review is not appropriate here.

Perception FOR action

The approaches we are describing as “perception FOR action,” maintain that perception serves goals of action. As such, perceptual mechanisms and perceptual representations would need to take into account both constraints on action as well as particular goals of action. While not claiming that all perceptual processing serves action, Goodale and Milner (1992; Milner and Goodale 2008) argued that there are two separate visual systems of processing in the brain, one of which is devoted to guiding action (see also Ungerleider and Mishkin, 1982). One stream, termed the dorsal or “how” stream, supports visual guidance of action, while the other, termed the ventral or “what” stream, supports conscious object recognition and visual representation. The evidence for this approach came first from neuropsychological patients who had one system preserved (both functionally and neurologically) but the other severely damaged. These patients clearly showed that one system could function without access to the representations of the other. For example, patient DF (Milner and Goodale, 2006) could not identify everyday objects following a lesion to the ventral stream, but could accurately grasp and act on them.

Following the evidence from patients, healthy individuals responding to visual illusions either by acting directly or providing perceptual judgments have produced more evidence in favor of the two visual streams approach. For example, Aglioti, DeSouza, and Goodale (1995) investigated size perception in both streams by using the Ebbinghaus illusion. This is a common illusion in which two circles of the same size are surrounded by either larger circles or smaller circles. Their contexts make them appear to differ in size, even though they do not. Participants who consciously reported on the perceptual size of the inner circles judged them to be different. The researchers suggested that the “what” stream provided the information for these judgments given that they were conscious. However, when asked to reach out to grasp the inner circles, the differences in size disappeared. Participants’ grips were similar across the two contexts, suggesting

that the “how” or visually guided action stream was unaffected by the illusion. This work, as well as that done on other illusions such as the Müller-Lyer (Gentilucci, Daprati, Gangitano, Saetti, and Toni, 1996; Westwood, Heath, and Roy, 2000; Wraga, Creem, and Proffitt, 2000) and Ponzo (Stöttinger and Perner, 2006) suggests that there is a dissociation between the “what” and “how” streams. The former is specialized for understanding details and features in a visual scene, while the latter is responsible for determining spatial locations and guidance of action. It is important to note, though, that the evidence for the two visual streams has been controversial (Glover, 2004; Schenk and McIntosh, 2010). Milner and Goodale (2008) have recently revised their two visual streams view to emphasize that the two systems have many connections and that actions may require information from the ventral stream, suggesting that the streams are not completely dissociated. The more recent evidence on a lack of total dissociation suggests to us that a characterization of this approach as perception FOR action may be better than describing perception and action as separate, as was suggested in the original proposal of the two visual streams.

A different perception FOR action approach is one that Proffitt and Linkenauger (in press) call the perception-as-phenotype approach. They (along with other colleagues) argue that explicit or conscious visual awareness is achieved by rescaling visual information about spatial layout of the environment to metrics of the body. These “body units” are then used to support decisions about which actions are possible. In other words, to be functional, perception must be scaled by some unit or ruler. They argue that the units are derived from the observer’s bodies and action capabilities that are relevant to the situation. Such an explanation makes evolutionary sense given observers always have their bodies with them to scale the world.

A growing body of literature provides support for this approach. For example, in studies of near distances (within or just outside of reach) observers judged targets that were just beyond reach as closer when they held a tool (Witt and Proffitt, 2008; Witt, Proffitt, and Epstein, 2005). Further, right-handed individuals perceived distances to be closer when reaching with their right hand than with their left (Linkenauger, Witt, Bakdash, Stefanucci, and Proffitt, 2009). According to the perception-as-phenotype approach, participants’ increased facility and capability with their dominant hand leads to a different unit for scaling of the space relevant to that hand. Interestingly, when the size of the hand is magnified, a rescaling of object sizes also occurs (Linkenauger, Ramenzoni, and Proffitt, 2010). Other effects of scaling with the body have been observed in spaces farther from the body. Stefanucci and Geuss (2009) showed that the width of the body may be used to estimate the size of apertures such that changes in body size result in changes in perceptual estimates. Eye height can also be used to scale distances to objects on the ground plane (Sedgwick, 1986). Moreover, when eye height changes estimates of the heights of objects may also be rescaled (Stefanucci and Geuss, 2010; Wraga and Proffitt, 2000). For excellent reviews of this approach as well as one that shows effects of action on perception, see Proffitt (2006) and Witt (2011). Overall, the approach suggests that perceptual representations are constructed to be applied to future action and thus are grounded in the body that will be performing the action.

Perception WITH action

The perception WITH action approach emphasizes that perception and action are inseparable. In this approach, both perception and action have direct contact with the environment. In other words, perceptual representations are not constrained or scaled by actions, but rather action and perceptual representation are mutually constrained by the environment.

The ecological approach as proposed by Gibson (1966, 1979) is an example of perception arising from the detection of sensory information WITH action. In other words, perception and action are inseparable, because they rely on one another. However, Gibson's approach does not require representations. Instead, he argues that perception is *direct*. Specifically, he claimed that the properties of the perceived environment (mostly those related to the guidance of action) are not ambiguous, but rather patterned, especially when taking into account movement and action. Thus, as the observer moves around, the structure of the light will be revealed along with the properties of the environment (Michaels and Carello, 1981; Shaw, Turvey, and Mace, 1982). Indeed, Fajen, Riley, and Turvey (2008) state that this allows observers to "achieve direct epistemic contact with their environments; that is, that they can know their environments in a way that is unmediated by internal representations" (p. 80). This approach is in contrast to the idea that information for perception is ambiguous and so requires some sort of inference or processing before it can be deciphered into a three-dimensional representation of the world. In the latter case, perception is not direct; it is an *indirect* interpretation of the environment based on the sensory information acquired by the retina and cognitive inferential processes that are applied to the stimulus.

Though indirect theories have merit when discussing reasons for visual illusions and other phenomena, they do not provide a model for how perception and action could dynamically interact over time. Such dynamic interaction must take place given that action requires movement and this leads to changing stimulus information at the eye. For example, David Lee and J. R. Lishman (Lee, 1974, 1976; Lee and Lishman, 1977) did extensive work examining the changes in optical information (termed arrays) that occur when observers act, thereby allowing them to discover ways in which to perform very complex actions like catching balls and hitting them. To catch an object, it is important for observers to anticipate when the object will come into contact with them. Lee (1976) found that time-to-contact (TTC) can be perceived by focusing on the size of the object and the change in its size over time (optical expansion). Estimations of speed and distance were not necessary to execute a successful catch. Though more recent work has contested the sole use of TTC in actions like catching (Hecht and Savelsbergh, 2004; Tresilian, 1999), Lee's work inspired others to search for invariants in the optical array that could lead to coordinated behaviors without need for representation. In addition to TTC, new work suggests that to make a successful catch, one must also detect the passing distance of the ball (Gray and Sieffert, 2005). Constant across these examples is the investigation of perception-action relationships in dynamic settings that are unfolding over time. It is also important to note that for skilled actions like catching, observers may not be *tuned* to the appropriate information to pick up in the environment when they begin to learn that skill. However, with practice, they can begin to identify which optical variables are most useful for guiding their actions (Jacobs and Michaels, 2006; van der Kamp, Savelsbergh, and Smeets, 1997), which is especially important in the context of sports (Fajen, Riley, and Turvey, 2008).

Also related to the study of spatial perception and action is Gibson's notion of *affordances* (1977). Perhaps the most well-known aspect of the ecological approach, affordances are the opportunities for action in the environment that are perceived by the observer depending on her intentions. For example, a chair affords sitting when an observer needs a place to rest and a tree affords climbing if an observer needs to flee. Like the rest of the optical array, Gibson proposed that affordances can be directly perceived in the light reflecting off the environment. Moreover, they are dependent upon the observer's size and shape as it relates to the properties of the environment. A 5 foot tall observer may not be able to climb a tree where the lowest branch is 6 feet. Thus, affordances readily demonstrate the perception WITH action

characterization given they rely on properties of both the observer and the environment to be perceived.

A large body of empirical work supports the notion of affordances. Here, we discuss just a few studies related to the perception of affordances at farther distances. To begin, Warren (1984) showed that people report being able to step onto an object if it is less than 0.88 times their leg length. Mark (1987) found that people could adjust to changes in their height (achieved by asking people to wear blocks under their shoes) when estimating what they could sit on. Stefanucci and Geuss (2010) found that adding similar blocks to observers' feet also affected their judgments of what they could walk under. Warren and Whang (1987) asked participants to decide whether they could walk through apertures of different sizes without rotating their shoulders. They found that both body size and eye height information contributed to their decisions about what was passable. Moreover, these judgments can be made in virtual environments where visual cues can be manipulated to determine their effect on perceived affordances. Geuss and colleagues (Geuss, Stefanucci, de Benedictis-Kessner, and Stevens, 2010) found no difference in judgments of whether an aperture afforded passage in a real environment as compared to a visually matched virtual environment. Fath and Fajen (2011) systematically manipulated the availability of eye height information and dynamic information (head sway and stride length) for passing through apertures in virtual environments. They found that performance was no different across various cue availability manipulations, suggesting that affordances for passage may rely on cues other than just eye height.

Perception AS action

The final approach is perception AS a form of action. Drawing inspiration from Merleau-Ponty (1948/1964), Gibson (1979) and Ballard (1996), Noë (2004, p. 1) provides a modern summary of this enactive approach: "Think of a blind person tap-tapping his or her way around a cluttered space, perceiving that space by touch, not all at once, but through time, by skillful probing and movement. This is, or at least ought to be, our paradigm for what perceiving is." O'Regan and Noë (2001) argue that perception is a form of sensorimotor bodily skill. They cite cases of experiential blindness, in which surgery restores sight to congenitally blind patients. However, patients are unable to understand their newly found sensations such as experiences of lights, colors, and edges, suggesting that this surgery restores visual sensations but not perception. Instead, perceptual meaning is derived from the sensorimotor significance of these patterns of light. As behavioral evidence for this phenomenon, Nöe cites the effects of left-right inverting prism glasses in people with normal vision. With these prism goggles, what would normally be seen on the right side of space is sent to the right side of the retina (instead of the left, which is the normal state of affairs). Instead of an inversion of visual experience, observers experience a kind of blindness, such that they are temporarily unable to connect the pattern of light to sensorimotor significance.

Another clear example of the perception AS action approach is the theory of event coding (TEC), or the common coding approach proposed by Prinz, Hommel, and colleagues (e.g. Hommel, Müsseler, Aschersleben, and Prinz, 2001). In their framework, perception and action are virtually inseparable because they share a common representational code. To be fair, the proponents of this approach do not claim to have a theory explaining all of the potential perception and action phenomena, but rather what they call late perception and early action (i.e. action planning). Given this, one might consider this approach as also fitting into the perception FOR action section. The TEC framework is clearly different than the ecological approach because it supports representations as underlying perception and action. However, it does not adhere to

traditional information-processing (i.e. those most often considered representational) models, because these models generally separate representations used for perception and action and study these phenomena in isolation. Although both ecological and information-processing models contributed to the TEC framework, they are clearly different.

The main tenet of the TEC approach is that perception and action planning share a common representational code. Thus, perceived and produced events are related through mutual interaction of their representations. Like the ecological approach, the TEC framework argues that perception is functional in that it can produce adaptive actions. Also, the progression from perceptual representation to executed action plan is not thought to be linear. So, important to this framework is the notion that perception may even require action. We must move around the world to acquire more sensory input and information, which then leads to sensorimotor coordination also resulting from the intentions of the observer/actor. This means that both action and perception codes are related in that they are concerned with distal (also termed extrinsic) events. However, they are interactive only when they are both related to a specific extrinsic feature of those distal events. Situational demands may drive the overlap of perceptual and action representations by weighting features that are particularly relevant for a given task, regardless of code. In perception, feature weighting likely occurs through attention, whereas with action, feature weighting is related to the intention of the observer. Both result in the anticipation and preparation for upcoming important events.

Support for this framework in spatial perception derives from many paradigms of research, including both behavioral and neuroscience work. Early evidence supporting TEC came from work on spatial, stimulus-response (S-R) compatibility paradigms (Simon, 1967; Wallace, 1971, 1972). In these studies, participants are asked to respond to stimuli that correspond to the spatial location where the response is made or not. For instance, a stimulus that appears to the right of the participant (either auditory or visual) will be responded to more quickly if the location of the to-be-executed response is also on the right. Importantly, this effect is not driven by the location of the effector (e.g. the right hand). Instead, it is the location of the response that matters most. Even when participants crossed their hands in order to make their responses (i.e. now the right hand is responding to the stimuli on the left), the correspondence between the stimulus and the response location produced the fastest responses. This is true even if responding when holding sticks rather than using one's fingers (Riggio, Gawryszewski, and Umiltà, 1986).

These S-R compatibility effects are not limited to static stimuli. Michaels (1988) displayed stimuli that were either on the right or left hand side of a screen. One object would then begin moving to the opposite side of the screen, which would signal the observer to respond. If the object's movement direction corresponded to the response location, then responses were facilitated, suggesting that dynamic properties of events can activate feature codes that enhance responses. If observers are asked to respond by making a particular hand gesture, then work by Stürmer, Aschersleben, and Prinz (2000) shows that conflicting gestures presented before cueing the response may interfere with the time that it takes participants to act. For instance, when observers see static images of a non-corresponding hand gesture (a grasp) and then are asked to produce a finger movement in response, they will be slower to act. This interference also occurs if a dynamic movie of a hand gesturing is played prior to the cue to respond. End state of the response action was achieved at a faster rate when the image or action viewed on the screen corresponded to the response action goal state. This enhancement in performance was predicted by TEC when the end-state representation was associated with the action code. However, it is also important to note that when representations completely overlap or are mostly shared, it may be harder to synchronize them (Aschersleben and Prinz 1995).

Summary and conclusions

In this review, we describe a novel strategy for categorizing the many ways in which perception and action have been studied, namely, by using prepositions to label the nature of the relationship as it has been investigated across the various approaches. However, we acknowledge that these categories may overlap. For example, Gibson's ecological approach is categorized as a perception WITH action approach, but it also has some connection to the work proposed in the perception FOR action section (e.g. the perception-as-phenotype approach) or the perception AS action section given perception is argued to be direct and without need for representation. Likewise, the TEC framework in the perception AS action section is not easily dissociable from the perception-as-phenotype approach in the perception FOR action section. If the body is being used to scale perception, which is then used for action, then a common coding system could underlie both constructs and still be consistent with both approaches. Nevertheless, we believe that thinking about the nature of the relationship between perception and action is important given the lack of a unified approach, and hope that our categorizations may help decipher commonalities and differences among these approaches.

References

- Aglioti, S., DeSouza, J. F., and Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. *Current Biology*, 5(6), 679–85.
- Aschersleben, G., and Prinz, W. (1995). Synchronizing actions with events: The role of sensory information. *Perception and Psychophysics*, 57(3), 305–17.
- Ballard, D. H. (1996). On the function of visual representation. In K. Akins (Ed.), *Vancouver Studies in Cognitive Science: Vol. 5. Perception* (pp. 111–31). New York: Oxford University Press. Repr. in A. Noë and E. Thompson (Eds.), *Vision and mind: Selected readings in the philosophy of perception* (pp. 459–79). Cambridge MA: MIT Press, 2002.
- Creem-Regehr, S. H., and Kunz, B. R. (2010). Perception and action. *Wiley Interdisciplinary Reviews: Cognitive Science*, 1(6), 800–10.
- Fajen, B. R., Riley, M. A., and Turvey, M. T. (2008). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology*, 40(1), 79–107.
- Fath, A. J., and Fajen, B. R. (2011). Static and dynamic visual information about the size and passability of an aperture. *Perception*, 40(8) 887–904.
- Gentilucci, M., Daprati, E., Gangitano, M., Saetti, M. C., and Toni, I. (1996). On orienting the hand to reach and grasp an object. *NeuroReport*, 7, 589–92.
- Geuss, M., Stefanucci, J. K., de Benedictis-Kessner, J., and Stevens, N. R. (2010). A balancing act: Physical balance, through arousal, influences size perception. *Attention, Perception, & Psychophysics*, 72, 1890–1902
- Gibson, J. J. (1966). *The senses considered as perceptual systems*. Boston: Houghton Mifflin.
- (1977). The theory of affordances. In R. Shaw and J. Bransford (Eds.), *Perceiving, acting, and knowing: Toward an ecological psychology* (pp. 67–82). Hillsdale, NJ: Lawrence Erlbaum.
- (1979). *The ecological approach to visual perception*, Hillsdale, NJ: Lawrence Erlbaum.
- Glover, S. (2004). Separate visual representations in the planning and control of action. *Behavioral and Brain Sciences*, 27(1), 3–78.
- Goodale, M. A., and Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, 15(1), 20–25.
- Gray, R., and Sieffert, R. (2005). Different strategies for using motion-in-depth information in catching. *Journal of Experimental Psychology: Human Perception and Performance*, 31(5), 1004–22.
- Hecht, H., and Savelsbergh, G. J. P. (2004). Theories of time-to-contact judgment. In H. Hecht and G. Savelsbergh (Eds.), *Advances in psychology: Vol. 135. Time-to-contact* (pp. 1–11). Boston: Elsevier.
- Hommel, B., Müsseler, J., Aschersleben, G., and Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences*, 24, 849–78.
- Jacobs, D. M., and Michaels, C. F. (2006). Lateral interception, I: Operative optical variables, attunement, and calibration. *Journal of Experimental Psychology: Human Perception and Performance*, 32(2), 443–58.

- Lee, D. N. (1974). Visual information during locomotion. In R. B. MacLeod and H. L. Pick Jr. (Eds.), *Perception: Essays in honor of James J. Gibson* (pp. 250–67). Ithaca, NY: Cornell University Press.
- (1976). A theory of visual control of braking based on information about time to collision. *Perception*, 5, 437–59.
- Lee, D. N., and Lishman, R. (1977). Visual control of locomotion. *Scandinavian Journal of Psychology*, 18(3), 224–30.
- Linkenauger, S. A., Ramenzoni, V., and Proffitt, D. R. (2010). Illusory shrinkage and growth: Body-based rescaling affects the perception of size. *Psychological Science*, 21(9), 1318–25.
- Linkenauger, S. A., Witt, J. K., Bakdash, J. Z., Stefanucci, J. K., and Proffitt, D. R. (2009). Asymmetrical body perception: A possible role for neural body representations. *Psychological Science*, 20(11), 1373–80.
- Mark, L. S. (1987). Eyeheight scaled information about affordances: A study of sitting and stair climbing. *Journal of Experimental Psychology: Human Performance and Perception*, 13, 371–83.
- Marr, D. (1982). *Vision*. New York: W. H. Freeman & Sons.
- Merleau-Ponty, M. (1948/1964). *Sense and non-sense* (H. Dreyfus and P. A. Dreyfus, Trans.). Evanston, IL: Northwestern University Press, 1964.
- Michaels, C. F. (1988). S-R compatibility between response position and destination of apparent motion: Evidence of the detection of affordances. *Journal of Experimental Psychology: Human Perception and Performance*, 14, 231–40.
- Michaels, C. F., and Carello, C. (1981). *Direct perception*. New York: Prentice-Hall.
- Milner, A. D., and Goodale, M. A. (2006). *The visual brain in action* (2nd ed.). Oxford: Oxford University Press.
- (2008). Two visual systems re-viewed. *Neuropsychologia*, 46(3), 774–85.
- Noë, A. (2004). *Action in perception*. Cambridge: MIT Press.
- Norman, J. (2002). Two visual systems and two theories of perception: An attempt to reconcile the constructivist and ecological approaches. *Behavioral and Brain Sciences*, 25, 73–144.
- O'Regan, J. K., and Noë, A. (2001). A sensorimotor approach to vision and visual consciousness. *Behavioral and Brain Sciences*, 24(5), 939–73.
- Proffitt, D. R. (2006). Embodied perception and the economy of action. *Perspectives on Psychological Science*, 1(2), 110–22.
- (2008). An action-specific approach to spatial perception. In R. L. Klatzky, M. Behrmann, and B. MacWinney (Eds.), *Embodiment, ego-space, and action* (pp. 177–200). Mahwah, NJ: Erlbaum.
- Proffitt, D. R., and Linkenauger, S. A. (2013). Perception viewed as a phenotypic expression. In W. Prinz, M. Beisert, and A. Herwig (Eds.), *Action science*. Cambridge, MA: MIT Press.
- Pylyshyn, Z. (1999). Is vision continuous with cognition? The case for cognitive impenetrability of visual perception. *Behavioral and Brain Sciences*, 22(3), 341–65. (Discussion, 366–423.)
- Riggio, L., Gawryszewski, L. G., and Umiltà, C. (1986). What is crossed in crossed-hand effects? *Acta Psychologica*, 62, 89–100.
- Schenk, T., and McIntosh, R. D. (2010). Do we have independent visual streams for perception and action? *Cognitive Neuroscience*, 1(1), 52–62.
- Sedgwick, H. A. (1986). Space perception. In K. Boff, L. Kaufman, and J. Thomas (Eds.), *Handbook of perception and human performance* (Vol. 1). New York: Wiley.
- Shaw, R. E., Turvey, M. T., and Mace, W. M. (1982). Ecological psychology: The consequence of a commitment to realism. In W. Weimer and D. Palermo (Eds.), *Cognition and the symbolic processes* (Vol. 2, pp. 159–226). Hillsdale, NJ: Erlbaum.
- Simon, H. A. (1967). An information-processing explanation of some perceptual phenomena. *British Journal of Psychology*, 58, 1–12.
- Stefanucci, J. K., and Geuss, M. N. (2009). Big people, little world: The body influences size perception. *Perception*, 38(12), 1782–95.
- (2010). Duck! Scaling the height of a horizontal barrier to body height. *Attention Perception Psychophysics*, 72(5), 1338–49.
- Stöttinger, E., and Perner, J. (2006). Dissociating size representation for action and for conscious judgment: Grasping visual illusions without apparent obstacles. *Consciousness and Cognition: An International Journal*, 15(2), 269–84.
- Stürmer, B., Aschersleben, G. and Prinz, W. (2000). Correspondence effects with manual gestures and postures: a study of imitation. *Journal of Experimental Psychology: Human Performance and Perception*, 26(6), 1746–59.
- Tresilian, J. R. (1999). Abstract levels of motor control in prehension: Normal and pathological performance. *Human Movement Science*, 18(2–3), 219–39.

- Ungerleider, L. G., and Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale, and R. J. W. Mansfield (Eds.), *Analysis of Visual Behavior* (pp. 549–86). Cambridge, MA: MIT Press.
- van der Kamp, J., Savelsbergh, G., and Smeets, J. (1997). Multiple information sources in interceptive timing. *Human Movement Science*, 16(6), 787–821.
- Wallace, R. J. (1971). S-R compatibility and the idea of a response code. *Journal of Experimental Psychology*, 88, 354–60.
- (1972). Spatial S-R compatibility effects involving kinesthetic cues. *Journal of Experimental Psychology*, 93, 163–68.
- Warren, W. H. (1984). Perceiving affordances: Visual guidance of stair climbing. *Journal of Experimental Psychology: Human Perception and Performance*, 10(5), 683–703.
- Warren, W. H., and Whang, S. (1987). Visual guidance of walking through apertures: Body-scaled information for affordances. *Journal of Experimental Psychology: Human Perception and Performance*, 13(3), 371–83.
- Westwood, D. A., Heath, M., and Roy, E. A. (2000). The effect of a pictorial illusion on closed-loop and open-loop prehension. *Experimental Brain Research*, 134(4), 456–63.
- Witt, J. K. (2011). Action's effect on perception. *Current Directions in Psychological Science*, 20(3), 201–6.
- Witt, J. K., and Proffitt, D. R. (2008). Action-specific influences on distance perception: A role for motor simulation. *Journal of Experimental Psychology Human Perception and Performance*, 34(6), 1479–92.
- Witt, J. K., Proffitt, D. R., and Epstein, W. (2005). Tool use affects perceived distance, but only when you intend to use it. *Journal of Experimental Psychology: Human Perception and Performance*, 31(5), 880–88.
- Wraga, M., Creem, S. H., and Proffitt, D. R. (2000). Perception-action dissociations of a walkable Müller-Lyer configuration. *Psychological Science*, 11(3), 239–43.
- Wraga, M., and Proffitt, D. R. (2000). Mapping the zone of eye-height utility for seated and standing observers. *Perception*, 29(11), 1361–83.

11

BODILY RELATIVITY

Daniel Casasanto

Introduction

Our bodies are an ever-present part of the context in which we use our minds. Thinking depends on context. Therefore, our bodies could exert myriad influences on how and what we think. How can we identify ways in which our bodily interactions with the environment are shaping our brains and minds? One strategy is to investigate whether people with different kinds of bodies think differently, in predictable ways. This chapter reviews research exploring ways in which the particulars of people's bodies shape their words, thoughts, feelings, and choices, and ways in which our habits of body-world interaction determine how thoughts and feelings are implemented in our brains.

This research is motivated by the *body-specificity hypothesis* (Casasanto, 2009, 2011): to the extent that the content of the mind depends on our interactions with our environment, people with different kinds of bodies – who interact with the environment in systematically different ways – should tend to form correspondingly different neural and cognitive representations. The body-specificity hypothesis has now been validated by more than two dozen experiments, conducted in a variety of populations on four continents, using methods that range from questionnaires (e.g. Casasanto, 2009) and reaction time tasks (e.g. de la Vega, de Filippis, Lachmair, Dudschig, and Kaup, 2012) to analyses of spontaneous gesture (Casasanto and Jasmin, 2010), memory tasks (Brunyé, Gardony, Mahoney, and Taylor, 2012), lesion-outcome studies (e.g. Casasanto and Chrysikou, 2011), visual hemifield (VHF) manipulations (Brookshire and Casasanto, 2013), functional magnetic resonance imaging (fMRI; e.g. Willems, Hagoort, and Casasanto, 2010), electroencephalography (EEG; Brookshire and Casasanto, 2012), and transcranial direct current stimulation (tDCS; Brookshire, Graver, and Casasanto, 2013). The mental processes and cognitive domains that exhibit body specificity include action verb understanding (Willems *et al.*, 2010), idiom comprehension (de la Vega, Dudschig, Lachmair, and Kaup, in press), motor imagery (Willems, Toni, Hagoort, and Casasanto, 2009), emotional valence (e.g. Casasanto, 2009), and affective motivation (Brookshire and Casasanto, 2012).

In light of the amount and diversity of the data, these studies that support the body-specificity hypothesis can be considered to be the first wave of evidence for a theory of *bodily relativity* (Casasanto, 2011), which can be described by analogy to a theory of linguistic relativity. Language and the body are two particularly stable and omnipresent aspects of the context in which

we do our thinking, both of which act as crucial points of interface between the mind and the world, and thereby shape the way we think. Just as speakers of different languages come to think differently in various ways, via a variety of mechanisms (Boroditsky, 2011; Casasanto, 2012; Lupyan, 2012), so do people with different kinds of bodies think differently, in various ways, via a variety of mechanisms that can have subtle or dramatic effects on brain and behavior.

Body specificity of action language and motor imagery

Initial tests of the body-specificity hypothesis used handedness as a “fruit fly”: a simple model system for testing broad principles. Unlike actual fruit flies, the hands are indispensable in our daily lives, mediating countless interactions between people and their environment – and importantly, different people use their hands differently, in some ways that are easy to observe and quantify.

Right- and left-handers often perform the same actions differently. When people throw a ball, sign a check, or grasp a coffee mug they usually use their dominant hand. Do differences in how people perform actions influence the way they imagine actions and process action language? To find out, my collaborators and I used fMRI to compare right- and left-handers’ brain activity during motor imagery and action verb understanding.

Imagined actions

In one experiment, participants were asked to imagine performing actions while lying perfectly still in the fMRI scanner. They imagined some actions that are usually performed with the dominant hand (scribble, toss) and some actions performed with other parts of the body (kneel, giggle). Mental imagery for hand actions corresponded to different patterns of activity in right- and left-handers’ motor systems. Left-hemisphere motor areas were activated in right-handers, but right-hemisphere motor areas were activated in left-handers (Willems *et al.* 2009). People with different kinds of bodies imagine the same actions differently, in this case using opposite hemispheres of the brain.

Motor action and verb meaning

A similar pattern was found when people read words for actions they usually perform with their dominant hands or with other parts of the body. When right-handers read words for hand actions they preferentially activated the left premotor cortex, an area used in planning actions with the right hand. Left-handers showed the opposite pattern, activating right-hemisphere premotor areas used for planning left-hand actions (Willems *et al.*, 2010). This was true even though they were not asked to imagine performing the actions, or to think about the meanings of the verbs. Further fMRI experiments confirmed that activation during action verb reading was not due to conscious imagery of actions (Willems, Toni, Hagoort, and Casasanto, 2010).

Do the *meanings* of action verbs differ between right- and left-handers? One way to address this question is to determine whether the motor areas that show body-specific patterns of activation play a functional role in verb processing. We used theta-burst repetitive transcranial magnetic stimulation (rTMS) to modulate neural activity in the premotor hand areas identified in our earlier fMRI study. Participants’ ability to distinguish meaningful manual action verbs from pseudo-words was affected by rTMS to the premotor cortex in the hemisphere that controls their dominant hand, but not in the other hemisphere. The rTMS to the hand areas had no effect on processing non-manual action verbs, which served as a control. These data

suggest that, when people read words like *grasp*, neural activity in the premotor area that controls the dominant hand is not an epiphenomenon, or a downstream consequence of semantic processing. Rather, body-specific activation of the motor system plays a functional role in processing language about hand actions (Willems, Labruna, D’Esposito, Ivry, and Casasanto, 2011). People tend to understand verbs as referring to actions they would perform with their particular bodies – not to a Platonic ideal of the action, or to the action as it is performed by the majority of language users. In this sense, people with different bodies understand the same verbs to mean something different.

These results are also informative about the kind of experience that people simulate when understanding action verbs: seeing actions or performing actions. Following Pulvermüller (2005), numerous studies have shown effector-specific activity cued by action verbs: hand areas respond selectively to hand-related verbs, foot areas to foot-related verbs, etc. Based on previous studies, however, it was not clear to what extent the motor component of action word meanings reflects actions we have observed others performing with their bodies (*allocentric simulation*) or actions we have performed ourselves (*egocentric simulation*). The allocentric possibility predicts that neurocognitive representations of manual action word meanings should be similar in right- and left-handers, since presumably everyone observes about the same proportion of right- and left-handed actions by other people. The discovery that motor activity associated with manual action words is body specific supports the egocentric possibility and suggests that, at least by default, people implicitly simulate their own prior or potential actions when understanding action words.

Body specificity of emotion

Abstract concepts of things we can never perceive with the senses or act upon with the muscles are the hard case for any theory that foregrounds the role of bodily experience in constructing the mind. Beyond the concrete domain of action, how might bodily experience shape mental representations of more abstract ideas like *goodness* and *badness*, *victory* and *loss*, *deceit* and *honesty*? Like many abstract concepts, these notions carry either positive or negative emotional valence. Affective valence (i.e. positivity or negativity) and motivation (i.e. the predisposition to approach or withdraw from physical and social situations) appear to be grounded in patterns of body-specific motor experience.

Emotional valence: choosing sides

Across languages and cultures, good things are often associated with the right side of space and bad things with the left. This association is evident in positive and negative idioms like *my right-hand man* and *two left feet*, and in the meanings of English words derived from the Latin for “right” (*dexter*) and “left” (*sinister*).

Beyond language, people also conceptualize good and bad in terms of left-right space, but not always in the way linguistic and cultural conventions suggest. Rather, people’s implicit associations between space and valence are body specific. When asked to decide which of two products to buy, which of two job applicants to hire, or which of two alien creatures looks more trustworthy, right- and left-handers respond differently. Right-handers tend to prefer the product, person, or creature presented on their right side but left-handers tend to prefer the one on their left (Casasanto, 2009). This pattern persists even when people make judgments orally, without using their hands to respond. Children as young as five years old already make evaluations according to handedness and spatial location, judging animals shown on their dominant

side to be nicer and smarter than animals on their non-dominant side (Casasanto and Henetz, 2012).

The implicit association between valence and left-right space influences people's memory and their motor responses, as well as their judgments. In one experiment, participants were shown the locations of fictitious positive and negative events on a map, and asked to recall the locations later. Memory errors were predicted by the valence of the event and the handedness of the participant: right-handers were biased to locate positive events too far to the right and negative events too far to the left on the map, whereas left-handers showed the opposite biases (Brunyé *et al.*, 2012). In reaction time tasks, right- and left-handers were faster to classify words as positive when responding by pressing a button with their dominant hand, and faster to classify words as negative when responding with their non-dominant hand (de la Vega *et al.*, 2012).

Left-handers have no choice but to use verbal idioms that suggest the right side is the good side: lefties cannot use *two left feet* to mean graceful, or refer to the correct answer as *the left answer*. Yet, one experiment suggests that left-handers process these idioms differently than right-handers. Left-handers responded slower than right-handers when asked to judge highly conventional good-is-right and bad-is-left idioms, but there was no difference between groups when participants judged literal left-right expressions or handedness-irrelevant metaphors (de la Vega *et al.*, in press).

Beyond the laboratory, the association of “good” with the dominant side can be seen in left- and right-handers’ spontaneous speech and gestures. In the final debates of the 2004 and 2008 US presidential elections, positive speech was more strongly associated with right-hand gestures and negative speech with left-hand gestures in the two right-handed candidates (Bush, Kerry), but the opposite association was found in the two left-handed candidates (McCain, Obama; Casasanto and Jasmin, 2010). Body-specific associations between space and valence have visible consequences for the way people communicate about positive and negative ideas.

How using your hands can change your mind

Why do right- and left-handers think differently in this way? These results cannot be predicted or explained by conventions in language and culture, which consistently associate “good” with “right” and “bad” with “left.” Instead, implicit associations linking valence with left-right space appear to be created as people interact with their physical environment. In general, greater motor fluency leads to more positive feelings and evaluations: people like things better when they are easier to perceive and interact with (e.g. Ping, Dhillon, and Beilock, 2009). Bodies are lopsided. Most of us have a dominant side and a non-dominant side, and therefore interact with the physical environment more fluently on one side of space than on the other. As a consequence right-handers, who interact with their environment more fluently on the right and more clumsily on the left, come to implicitly associate “good” with “right” and “bad” with “left,” whereas left-handers form the opposite association (Casasanto, 2009).

To test this proposal, Evangelia Chrysikou and I studied how people think about “good” and “bad” after their dominant hand has been handicapped, either due to brain injury or to something much less extreme: wearing a bulky ski glove. One experiment tested space-valence mappings in stroke patients with hemiparesis (weakness or paralysis) on either their right or left side following damage to the opposite hemisphere of the brain. The patients, who had all been right-handed prior to brain injury, performed a task known to reveal body-specific space-valence associations in healthy participants. Patients who lost the use of their left hand post-stroke showed the usual right-is-good pattern. By contrast, patients who had lost the use of their right hand associated “good” with “left,” like natural left-handers.

A similar reversal was found in healthy university students who performed a motor fluency task while wearing a cumbersome glove on either their left hand (which preserved their natural right-handedness), or on their right hand, which turned them temporarily into left-handers. After about twelve minutes of lopsided motor experience, participants removed the glove and performed a test of space-valence associations, which they believed to be unrelated. Participants who had worn the left glove still thought “right” was “good,” but participants who had worn the right glove showed the opposite left-is-good bias, like natural lefties (Casasanto and Chrysikou, 2011).

Motor experience plays a causal role in shaping abstract thoughts. Even a few minutes of acting more fluently with the left hand can change right-handers’ implicit associations between space and emotional valence, causing a reversal of their usual judgments. People generally have the impression that their judgments are rational and their concepts are stable. But if wearing a glove for a few minutes can reverse our usual decisions about what is good and bad, the mind may be more malleable than we thought.

The effects of short-term motor asymmetries are presumably temporary, but the same associative learning mechanisms that changed people’s judgments in the laboratory training task may result in the long-term changes we found in stroke patients, and may shape natural right- and left-handers’ space-valence associations in the course of ordinary motor experience. Using our asymmetrical bodies, and therefore interacting with the physical environment more fluently on one side of space than the other, may serve as a kind of natural “motor training.”

Is valence differently lateralized in right- and left-handers’ brains?

The discovery of body-specific associations between space and valence motivates a re-evaluation of an influential model of emotional valence in the brain, according to which the left hemisphere is specialized for positive emotions and the right-hemisphere for negative emotions (e.g. Davidson and Sutton, 1995). Dozens of studies have used lateralized stimulus or response tasks to investigate the hemispheric correlates of valence, most typically VHF manipulations in which positive and negative stimuli (e.g. happy/sad faces) were presented briefly to the right or left of a central fixation point, to send visual information to the contralateral hemisphere. Studies manipulating the right vs. left VHF have been interpreted as showing that positive emotions are processed in the left hemisphere and negative emotions in the right hemisphere (e.g. Reuter-Lorenz and Davidson, 1981). At least this appears to be the case in right-handers. Over the past three decades, there have been occasional reports of deviations from this well-established pattern when VHF-emotion studies have been conducted in left-handers (e.g. Everhart, Harrison, Crews, 1996; Natale, Gur, and Gur, 1983). The left-handers’ data have been somewhat inconsistent, and have been largely interpreted as noise, but they raise the possibility that hemispheric specialization for valence could vary with handedness. An alternative possibility, however, is that only *responses* in VHF-emotion studies could vary with handedness.

Although the goal of these VHF studies has been to determine hemispheric organization of emotion, there are reasons to reconsider whether they can be interpreted with respect to that goal – and whether valence is differently lateralized in right- and left-handers’ brains (or, indeed, lateralized at all). Body-specific space-valence associations provide an alternative explanation for *all* previous VHF-emotion experiments, and for related experiments using lateralized auditory or haptic presentation of emotional stimuli (e.g. McFarland and Kennison, 1989) or lateralized manual outputs (e.g. Kong, 2013; Root, Wong, and Kinsbourne, 2006). Stimuli presented to the right VHF appear on the participant’s right side of space; stimuli presented to the left VHF appear on the participant’s left side. Therefore, presenting positive and negative stimuli on a

participant's "good" and "bad" side could produce "VHF effects" even if participants were not selectively processing the stimuli in one hemisphere or the other. Many of the space-valence experiments reviewed above show that laterally presented stimuli can activate space-valence associations even when the stimuli are processed slowly and presumably *bi-hemispherically*. Therefore, there is no need to posit hemispheric specialization for emotion to account for emotional VHF effects.

In short, in light of what we have learned in this program of research so far, it appears that decades of emotional VHF experiments may have been drastically misinterpreted. If emotional VHF effects are, in fact, due to body-specific associations in memory, created by habitual asymmetries in manual motor fluency, then two predictions follow. First, right- and left-handers should show opposite patterns of responses on an emotional VHF task. Second, response patterns should *reverse* with motor training that temporarily reverses hand dominance (as in Casasanto and Chrysikou, 2011).

A test of this proposal supported both of these predictions. First, in a version of a classic VHF experiment on emotional face judgments, right-handers were more likely to judge neutral faces to be positive when they appeared on the right of fixation and to be negative when they appeared on the left – but left-handers showed the opposite pattern (Brookshire and Casasanto, 2013). The strength of the body-specific judgment bias varied parametrically with the participant's degree of handedness, as measured by participants' scores on the Edinburgh Handedness Inventory (EHI; Oldfield, 1971). Right- and left-handers showed opposite emotional VHF effects.

In a second experiment, right-handers performed the ski-glove training task (Casasanto and Chrysikou, 2011) before the VHF face task. After training, participants who had worn the glove on their right hand (becoming transiently left-handed in the relevant regard) were more likely to judge neutral faces to be positive when they appeared on their left of fixation and to be negative when they appeared on the right – like natural left-handers. Twelve minutes of motor experience can completely reverse the emotional VHF effect typically found in right-handers (in our study and in many others like it). It is more likely that this twelve-minute training intervention was able to alter fluency-based associations between space and valence in participants' memory than to completely reverse any gross hemispheric specialization for valence.

Summary of body-specific space-valence associations

Right- and left-handers form the opposite implicit associations between left-right space and positive and negative emotional valence. Each group tends to associate "good" with their dominant side of space and "bad" with their non-dominant side. For right-handers, these associations accord with linguistic and cultural conventions that link "good" with "right," but left-handers' implicit associations contradict these conventions. These implicit associations appear to be formed as people interact with their environment more fluently on their dominant side of space and more clumsily on their non-dominant side, as evidenced by stroke patients and laboratory participants who have their naturally dominant hand impaired (permanently or transiently) and show a corresponding reversal of their space-valence association.

This discovery suggests that numerous behavioral studies previously interpreted as evidence for hemispheric specialization of positive and negative valence should be reinterpreted. The results of VHF-emotion tasks (and other lateralized stimulus and response tasks) can be explained in terms of previously undocumented mnemonic associations between space and valence. These data do not require an explanation in terms of hemispheric specialization, which seems very

unlikely to be correct in light of evidence that responses on a VHF-valence task can be completely reversed by a few minutes of motor training. Reinterpreting VHF-emotion tasks in terms of body-specific space-valence associations – rather than hemispheric specialization – reconciles a large body of behavioral data with newer neuroimaging data that cast doubt on the seemingly well-supported “valence model” according to which positive and negative valence were thought to be differently lateralized in the hemispheres (Berkman and Lieberman, 2010; Harmon-Jones, Gable, and Peterson, 2010), thus clarifying theories of the cortical substrates of emotion.

Motivation and motor action: the sword and shield hypothesis

Neuroimaging studies that have called the hemispheric laterality of *emotional valence* into question have, at the same time, strengthened the evidence for hemispheric specialization of *affective motivation* (Berkman and Lieberman, 2010; Coan and Allen, 2003; Harmon-Jones, 2003). More than seventy EEG studies show approach and avoidance motivational states are differently lateralized in the frontotemporal cortices (Harmon-Jones *et al.*, 2010). At least this is true in right-handers. Decades after the first EEG-motivation study in right-handers was published, there were no tests in left-handers.

Why might a test of motivational asymmetries in left-handers’ brains be fruitful? It is important to state that testing for handedness-related differences in hemispheric specialization is not necessarily of theoretical interest, per se: many of the hemispheric differences that have been documented were weak, unpredicted, unexplained, and their implications for scientific theorizing remain unclear. In the case of affective motivation, however, we had a focused reason for investigating whether the well-established hemispheric asymmetry in right-handers is also found in left-handers.

Emotional states are intimately linked to actions, and to the hands people use to perform them. In centuries past, sword fighters wielded the sword in the dominant hand to approach an enemy, and raised the shield with the non-dominant hand to avoid attack. The tendency to *approach* with the dominant hand and *avoid* with the non-dominant hand is evident in more ordinary motor actions, as well, including reflex actions. When startled, people reflexively raise the non-dominant hand to defend themselves (Coren, 1992), keeping the more skilful dominant hand out of harm’s way, and leaving it free for more complex approach actions.

In right-handers, the left hemisphere is specialized for approach emotions, and the right hemisphere for avoidance emotions (Harmon-Jones *et al.*, 2010). This means that, for right-handers, approach motivation is co-lateralized with the neural circuits primarily responsible for control of the dominant hand, and avoidance motivation with the circuits responsible for control of the non-dominant hand. This may be no mere coincidence. Approach motivation may be co-lateralized with dominant-hand motor control *because* the dominant “sword hand” is used preferentially for approach actions. Likewise, avoidance motivation may be co-lateralized with non-dominant-hand motor control because the non-dominant “shield hand” is used for avoidance actions. This is the *sword and shield hypothesis* (SSH; Brookshire and Casasanto, 2012; Casasanto, 2009).

This proposal makes a clear prediction: the hemispheric laterality of approach and avoidance motivation found previously in right-handers should reverse in left-handers, for whom cortical control of the “sword hand” and “shield hand” is reversed. To test this prediction, Geoffrey Brookshire and I measured alpha-band power (an inverse index of neural activity) in right- and left-handers during resting-state EEG, and analyzed hemispheric alpha-power asymmetries as a

function of the participants' trait approach motivational tendencies (measured by the BAS [behavioral activation system] scale; Carver and White, 1994). Stronger approach motivation was associated with more left-hemisphere activity in right-handers, but with more *right*-hemisphere activity in left-handers – indicating a complete reversal of hemispheric specialization for approach motivation (Brookshire and Casasanto, 2012).

A further study confirmed these EEG results using tDCS (which delivers a weak electrical current to the brain through the skull) to manipulate the level of neural activity in participants' left and right frontal lobes (Brookshire, Graver, and Casasanto, 2013). This study showed that the degree to which approach motivation is lateralized in the left vs. right hemisphere covaries continuously with the strength and direction of the participants' hand dominance, as measured by the EHI.

According to the “motivation model” of hemispheric specialization, which is supported by more than a hundred behavioral and neuroimaging studies, the left hemisphere is specialized for approach motivation and the right hemisphere specialized for avoidance motivation. But this conclusion – a cornerstone of affective neuroscience – appears to be incorrect: it appears to be a sampling artifact that resulted from the common practice of testing only strong right-handers in neuroimaging studies. The data demonstrating the body specificity of approach motivation suggest that there is no “approach hemisphere” and no “avoidance hemisphere.” Rather, approach motivation appears to be distributed across both hemispheres, consistent with (and perhaps because of) handedness-related differences in hemispheric specialization for manual motor control.

Conclusions

People with different kinds of bodies think differently, in predictable ways. Even highly abstract thoughts depend, in part, on the ways people interact with the physical environment using their particular bodies. The body shapes the mind on various timescales. To the extent that habits of body-world interaction are stable, the habits of mental representation they encourage should be stable over time; to the extent that they change, mental representations may change accordingly. Many other contextual factors influence the representations people form and the judgments they make, as well, and other factors may override body-specific influences at times. But the body is an ever-present part of the context in which we use our minds, and therefore has pervasive influences on the neurocognitive activity that constitutes our thoughts.

These first tests of the body-specificity hypothesis focused on how handedness, genetic or induced, influences brain and mind. On the basis of this bodily attribute, right- and left-handers tend to form systematically different mental images, create different word meanings, arrive at opposite judgments about the same objects in the world, and have a radically different cortical organization of affective motivation. Our hands are particularly important for interfacing with the physical and social environment, but there may be nothing special about the mechanisms by which using our hands shapes our brains and minds (e.g. associative learning), and body-specificity effects should extend beyond the initial test bed of handedness. The ways in which cognitive scientists could discover that bodily differences lead to cognitive differences are limited only by our imaginations.

Like research on linguistic relativity and cultural relativity, investigations of bodily relativity elucidate how patterns of experience give rise to corresponding habits of thinking, feeling, and communicating: how experience shapes our brains and minds. A further challenge is to determine how influences of linguistic, cultural, and bodily experiences combine to shape our mental lives.

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References

- Berkman, E., and Lieberman, M. (2010). Approaching the bad and avoiding the good: Lateral prefrontal cortical asymmetry distinguishes between action and valence. *Journal of Cognitive Neuroscience*, 22(9), 1970–79.
- Boroditsky, L. (2011). How language shapes thought. *Scientific American* (February), 63–65.
- Brookshire, G., and Casasanto, D. (2012). Motivation and motor control: Hemispheric specialization for approach motivation reverses with handedness. *PLoS One*, 7(4), e36036.
- (2013). Brief motor experience reverses visual hemifield effects for emotional faces. Poster presented at the 25th Annual Convention of the Association for Psychological Science, Washington, DC.
- Brookshire, G., Graver, C., and Casasanto, D. (2013). Motor asymmetries predict neural organization of emotion. In M. Knauff, M. Pauen, N. Sebanz, and I. Wachsmuth (Eds.), *Proceedings of the 35th Annual Conference of the Cognitive Science Society* (pp. 245–50). Austin, TX: Cognitive Science Society.
- Brunyé, T., Gardony, A., Mahoney, C. R., and Taylor, H. A. (2012). Body-specific representations of spatial location. *Cognition*, 23(2), 229–39.
- Carver, C. S., and White, T. L. (1994). Behavioral inhibition, behavioral activation, and affective responses to impending reward and punishment: The BIS/BAS scales. *Journal of Personality and Social Psychology*, 67, 319–33.
- Casasanto, D. (2009). Embodiment of abstract concepts: Good and bad in right- and left-handers. *Journal of Experimental Psychology: General*, 138(3), 351–67.
- (2011). Different bodies, different minds: The body specificity of language and thought. *Current Directions in Psychological Science*, 20(6), 378–83.
- (2012). Whorfian hypothesis. In *Oxford Bibliographies online: Anthropology*. New York: Oxford University Press.
- Casasanto, D., and Chrysikou, E. G. (2011). When left is “right”: Motor fluency shapes abstract concepts. *Psychological Science*, 22(4), 419–22.
- Casasanto, D., and Henetz, T. (2012). Handedness shapes children’s abstract concepts. *Cognitive Science*, 36, 359–72.
- Casasanto, D., and Jasmin, K. (2010). Good and bad in the hands of politicians. *PLoS One*, 5(7), e11805.
- Coan, J. A., and Allen, J. J. B. (2003). Frontal EEG asymmetry and the behavioral activation and inhibition systems. *Psychophysiology*, 40(1), 106–14.
- Coren, S. (1992). *The left-hander syndrome: The causes and consequences of left-handedness*. New York: Random House.
- Davidson, R. J., and Sutton, S. K. (1995). Affective neuroscience: The emergence of a discipline. *Current Opinion in Neurobiology*, 5, 217–24.
- de la Vega, I., de Filippis, M., Lachmair, M., Dudschig, C., and Kaup, B. (2012) Emotional valence and physical space: Limits of interaction. *Journal of Experimental Psychology: Human Perception and Performance*, 38(2), 375–85.
- de la Vega, I., Dudschig, C., Lachmair, M., and Kaup, B. (in press). Being someone’s right hand doesn’t always feel right: Bodily experiences affect metaphoric language processing. *Language and Cognitive Processes*.
- Everhart, D., Harrison, D., and Crews, W., Jr. (1996). Hemispheric asymmetry as a function of handedness: Perception of facial affect stimuli. *Perceptual and Motor Skills*, 82, 264–66.
- Harmon-Jones, E. (2003). Clarifying the emotive functions of asymmetrical frontal cortical activity. *Psychophysiology*, 40, 838–48.
- Harmon-Jones, E., Gable, P., and Peterson, C. (2010). The role of asymmetric frontal cortical activity in emotion-related phenomena: A review and update. *Biological Psychology*, 84, 451–62.
- Kong, F. (2013). Space-valence associations depend on handedness: Evidence from a bimanual output task. *Psychological Research*, 77(6), 773–79.

- Lupyan, G. (2012). Linguistically modulated perception and cognition: the label feedback hypothesis. *Frontiers in Cognition*, 3(54).
- McFarland, R. A., and Kennison, R. (1989). Handedness affects emotional valence asymmetry. *Perceptual and Motor Skills*, 68, 435–41.
- Natale, M., Gur, R. E., and Gur, R. C. (1983). Hemispheric asymmetries in processing emotional expressions. *Neuropsychologia*, 21(5), 555–65.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, 9, 97–113.
- Ping, R. M., Dhillon, S., and Beilock, S. L. (2009). Reach for what you like: The body's role in shaping preferences. *Emotion Review*, 1, 140–50.
- Pulvermüller, F. (2005). Brain mechanisms linking language and action. *Nature Reviews Neuroscience*, 6(7), 576–82.
- Reuter-Lorenz, P. A., and Davidson, R. J. (1981). Differential contributions of the two cerebral hemispheres to the perception of happy and sad faces. *Neuropsychologia*, 19, 609–13.
- Root, J. C., Wong, P. S., and Kinsbourne, M. (2006). Left hemisphere specialization for response to positive emotional expressions: A divided output methodology. *Emotion*, 6(3), 473–83.
- Willems, R. M., Hagoort, P., and Casasanto, D. (2010). Body-specific representations of action verbs: Neural evidence from right- and left-handers. *Psychological Science*, 21(1), 67–74.
- Willems, R. M., Labruna, L., D'Esposito, M., Ivry, R., and Casasanto, D. (2011). A functional role for the motor system in language understanding: Evidence from theta-burst TMS. *Psychological Science*, 22(7) 849–54.
- Willems, R. M., Toni, I., Hagoort, P., and Casasanto, D. (2009). Body-specific motor imagery of hand actions: Neural evidence from right- and left-handers. *Frontiers in Human Neuroscience*, 3(39), 1–9.
- (2010). Neural dissociations between action verb understanding and motor imagery. *Journal of Cognitive Neuroscience*, 22(10), 2387–2400.

12

EMBODIMENT AND LANGUAGE COMPREHENSION

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The ability to create and convey meaning is an ability that lies at the heart of the human ability to use language. The creation of meaning through language is central to our capacity to accomplish a range of intra- and interpersonal goals, and therefore a theory of “meaning making” (and, “meaning apprehension”) must have a key place in theories that explain the acquisition, comprehension, and production of language (Glenberg and Robertson, 2000). The goal of this chapter is to discuss one account of how language conveys meaning, the *embodied approach to language comprehension*. The aspect of the embodied approach that has received the most empirical and theoretical attention is the claim that the comprehension of sentences such as, “Meghan gave Michael a pen,” involves the construction of internal sensorimotor simulations of the content of the sentence. In this case, one might simulate a male and a female, and the arm action involved in transferring a pen from one person to another (e.g. Glenberg and Kaschak, 2002). We discuss the evidence for this claim, as well as criticisms of this embodied position. We also draw on recent proposals (e.g. Pickering and Garrod, 2013) to consider other ways that language can be considered “embodied.”

The symbol grounding problem

The phrase *embodied approach to language comprehension* is most often taken as a reference to the claim that linguistic meaning arises from sensorimotor simulations of the actions, events, and states that are described in language. Thus, comprehending an action verb such as *give* or *kick* involves the recruitment of the motor system to simulate giving and kicking actions (e.g. Glenberg and Kaschak, 2002; Hauk, Johnsrude, and Pulvermüller, 2004), understanding words and phrases describing visual motion involves the recruitment of the visual system to simulate moving objects (e.g. Meteyard, Bahrami, and Vigliocco, 2007), and understanding language about emotion involves internal simulation of emotional states (e.g. Havas, Glenberg, and Rinck, 2007). This claim of the embodied approach is supported by a growing body of evidence (reviewed in Fischer and Zwaan, 2008). Before discussing this evidence, however, we discuss the embodied approach within the context of a broader theoretical issue surrounding linguistic meaning, namely the *symbol grounding problem* (e.g. Harnad, 1990; Searle, 1980)

We describe the symbol grounding problem in terms of Harnad’s (1990) Chinese airport example. Imagine that you have just disembarked from a plane in China. You do not understand

Chinese, but have a Chinese dictionary. You decide to find the baggage claim, and look at the sign hanging from the ceiling for directions. The sign is written in Chinese, so you open the dictionary to find the first word on the sign. You find the word, and find that its definition is written in Chinese. No problem, you think, you'll just look up the first word of the definition in the dictionary. You do so, and find that the word is defined in Chinese as well. It is clear that no matter how much time you spend with the sign and the dictionary, you will never figure out what the words on the sign mean. This is the essence of the symbol grounding problem. Symbols that are abstract and arbitrary (such as words, whose form is abstracted away from, and arbitrarily related to, the things to which they refer) cannot be understood solely through their connection to other abstract, arbitrary symbols. They can only be understood by being grounded in some other representational format that is understood in and of itself. In the case of the Chinese airport, a picture of a suitcase along with an arrow pointing down one corridor would provide the grounding needed to understand the sign. Although you do not understand the words, you do understand the pictures, and can use this knowledge to develop an understanding of what the words mean. With respect to language, the embodied approach claims that the abstract, arbitrary symbols of language become meaningful by being grounded in knowledge about our bodies, and how our bodies interact with the world.

The symbol grounding problem provided an important impetus for the development of an embodied approach to language comprehension (e.g. Glenberg and Robertson, 2000). The embodied approach resolves the symbol grounding problem by asserting that abstract, arbitrary linguistic forms (e.g. words, phrases, abstract syntactic templates) are understood through their grounding in our bodies' systems of perception and action planning (Glenberg, 1997). To illustrate, consider the meaning of the word *violin*. Embodied approaches claim that the meaning of this word is rooted in sensorimotor experience with violins – perceptual and motor records of what they look like, what they sound like, what it feels like to hold one and draw a bow across its strings (if you have ever done so), and what it looks like to watch someone else play the instrument (which may be especially important if you have never done so yourself). In Barsalou's (1999) proposal, processing the word *violin* involves the recruitment of these perceptual records to internally simulate what violins look like, how they are played, the kinds of sound they make, and so on. These simulations are the basis of linguistic meaning. The simulations are understood in the same way as one understands real objects, actions, and events in the external world.

Claiming that embodied approaches resolve the symbol grounding problem relies on the assumption that we have a fundamental understanding of our bodies and how they act in, and interact with, the external environment. This claim resonates well with thinking about the evolution of cognition. It has been noted that the evolution of nervous systems is rooted in the need for organisms to move (*cognition is for action*; Wolpert, Ghahramani, and Flanagan, 2001). In evolutionary terms, there is a close relationship between body morphology, nervous system characteristics, and cognitive abilities (e.g. MacIver, 2009). For example, body symmetry (found in virtually all animals) is a characteristic that allowed for increased forward mobility, and also presaged the clustering of sense organs around the anterior end of the organism, which led to the development of brains (e.g. Grabowsky, 1994; Paulin, 2005; MacIver, 2009). The evolution of sense organs and nervous systems was strongly influenced by the nature of the organisms' bodies and how that body interacted with the environment (e.g. Engelhaaf *et al.*, 2002). MacIver (2009) notes that the ability to perceive information from the distal environment allowed for the development of more complex forms of cognition (such as planning), but these more complex forms of cognition are rooted in existing systems that allow us to act on our environment (see Walsh, 2003, for a discussion of how understanding abstractions such as time

is grounded in the neural circuitry involved in reaching for and grasping objects). Thus, our cognitive abilities (including the use of language) are inextricably bound up in a nervous system that evolved for the purpose of taking successful action in the environment (see Glenberg, 1997, for a discussion of this point).

It is worth noting that whereas the embodied approach has a straightforward approach to resolving the symbol grounding problem, other approaches to linguistic meaning that are on offer in the cognitive science community (e.g. semantic networks; the approaches represented by formalisms such as Landauer and Dumais' [1997] latent semantic analysis) either completely fail to resolve this problem or resolve the problem by acknowledging the need for some layer of "embodied" (i.e. perceptual or motor) representations within a larger semantic system. Space constraints do not permit a full airing of this issue (see de Vega, Glenberg, and Graesser, 2008, for a thorough approach to the matter), but it is our sense that a consideration of the symbol grounding problem provides a firm basis for why something like an embodied approach to language comprehension is needed to explain linguistic meaning – if linguistic symbols are not grounded in systems of perception and action planning, it is difficult to understand how they could convey meaning.

Embodiment and language comprehension: empirical studies

Embodied approaches to language comprehension hold that language is understood through the construction of sensorimotor simulations of the content of the linguistic input (e.g. Glenberg and Kaschak, 2002; Stanfield and Zwaan, 2001). This claim has been tested extensively over the past decade. In the following pages, we provide a selective overview of this empirical work.

Motor simulations

A major line of research on the embodiment of language comprehension involves the role that motor simulations play in the comprehension of words and sentences. An early example of this work is presented by Glenberg and Kaschak (2002). They asked participants to read (and make sensibility judgments on) sentences such as, "Meghan gave you a pen" or "You gave Meghan a pen." The first sentence describes action toward the body (you are receiving the pen), and the second sentence describes action away from the body (you are giving the pen away). To make sensibility judgments, participants needed to either produce an action toward their body (moving toward their body to press a button) or produce an action away from their body (moving away from the body to press a button). Participants were faster to execute the actions when the direction of action described in the sentence (toward or away from the body) matched the direction of action needed to make the sensibility judgment response (toward or away from the body). That is, the processing of a sentence about action affected the comprehender's ability to plan and execute action in the external environment.

A number of subsequent studies have expanded upon Glenberg and Kaschak's (2002) initial findings. In one series of studies, Zwaan and Taylor (2006) asked participants to read sentences while turning a knob to get from one phrase in the sentence to the next. They found that not only does one find motor-compatibility effects when participants produce a motor response after comprehending an entire sentence (as in Glenberg and Kaschak, 2002), but that one also finds localized motor-compatibility effects during the online processing of the sentence. Zwaan and Taylor (2006) report that motor effects arise when participants are reading the verb of the sentence, or when reading a word (such as an adverb) that modifies the way in which the action of the verb is being executed (Taylor and Zwaan, 2008). Thus, there seems to be relatively

localized motor activity during the online comprehension of a sentence (Zwaan and Taylor, 2006; Taylor and Zwaan, 2008; Glenberg *et al.*, 2008), as well as motor activity associated with the processing of an entire sentence (Glenberg and Kaschak, 2002; Borreggine and Kaschak, 2006).

The nature of the motor activity that arises during language comprehension has been further clarified in studies reported by Bub and Masson (2010; Masson, Bub, and Warren, 2008). Using a response device called the Graspasaurus, Bub and Masson examined the extent to which the processing of nouns (e.g. *calculator*) activates *functional* motor gestures (e.g. using the pointer finger to poke the keys of the calculator) and *volumetric* motor gestures (e.g. using an open hand grasp to pick the calculator up). Bub and Masson (2010) report that both functional and volumetric gestures are activated online during sentence processing, but only functional gestures remain active once the sentence has ended. Furthermore, Masson *et al.* (2008) report that functional gestures are activated even when the sentence does not describe explicit action on an object (e.g. “The man looked at the calculator”). Taken together, the various findings reported here suggest that motor information is elicited by the processing of both nouns and verbs, that this information is elicited during online comprehension, and persists to become a part of the final interpretation of the sentence.

The behavioral studies described above are complemented by the results of studies using fMRI and EEG techniques to observe motor activity during the comprehension of language (see Pulvermüller, 1999, for an overview). The most well-known finding in this area is Hauk *et al.*’s (2004) report that the processing of words such as *pick*, *kick*, and *lick* elicits motor activity in the hand, foot, and mouth areas of the motor cortex. A similar degree of motor specificity was reported by Tettamanti *et al.* (2005) and Buccino *et al.* (2005). Thus, there is a strong empirical case to be made that the comprehension of language about action involves the use of the neural systems that are involved in action planning and execution.

Perceptual simulations

A second major area of exploration for the embodied perspective has examined the perceptual simulations that arise during language processing. Zwaan and colleagues (Stanfield and Zwaan, 2001; Zwaan, Stanfield, and Yaxley, 2002; Zwaan, Madden, Yaxley, and Aveyard, 2004) used a paradigm in which participants read a sentence that specified some visual content (e.g. reading, “The eagle is in the sky,” should elicit a simulation of an eagle with outstretched wings). After reading the sentence, the participants viewed a picture of an object (e.g. an eagle), and had to indicate whether the object depicts something that was mentioned in the sentence. Zwaan and colleagues report that responses to the picture are faster when the content of the picture matches the content of the sentence (e.g. a picture of an eagle with outstretched wings) than when the picture mismatches the content of the sentence (e.g. a picture of an eagle with wings folded in).

Kaschak *et al.* (2005) report another set of experiments in which participants process sentences about visual motion (e.g. “The squirrel ran away from you” describes visual motion away from the body) while also viewing stimuli depicting motion. They find that participants are faster to respond to sentences when the concurrently presented visual stimulus depicts motion in the opposite direction as the sentences (e.g. watching motion toward the body, while processing a sentence about motion away from the body). The conflict that arises when the direction of the visual stimulus and the direction of motion in the sentence are the same is taken as evidence that the comprehension of sentences about visual motion involves the use of the neural mechanisms that are involved in the perception of motion in the external environment. A number of subsequent studies have produced evidence that the processing of language about

motion affects, and is affected by, the processing of visual stimuli (e.g. Bergen, Lindsay, Matlock, and Narayanan, 2007; Richardson and Matlock, 2007; Meteyard *et al.*, 2007). As in the case of motor simulations, the behavioral evidence for perceptual simulations is complemented by findings from neuroscience demonstrating that the processing of language about perceptual characteristics elicits activity in the neural regions associated with the processing of distal perceptual stimuli (see Martin, 2007, and Binder, Desai, Graves, and Conant, 2009, for reviews).

Simulation of emotion and abstractions

A more recent development in the embodied approach to language comprehension is to consider how embodied representations underlie the understanding of language about emotions and other kinds of abstract concepts. The simulation of emotion has been tackled by Glenberg and colleagues (Havas *et al.*, 2007; Havas, Glenberg, Gutowski, Lucarelli, and Davidson, 2010). One particularly striking finding from this program of research is reported by Havas *et al.* (2010). Their participants received injections of Botox in the muscles involved in frowning. These participants subsequently showed impairment in the comprehension of sentences involving negative emotion. Interfering with one's ability to physically express emotion thus interferes with one's ability to process sentences that trade on that emotion.

Much has been written about how embodied approaches can handle the understanding of abstract concepts (e.g. Lakoff and Johnson, 1980; Gibbs, 2011; Casasanto and Boroditsky, 2008; Barsalou, 1999). The general idea behind this work has been to illustrate how particular kinds of abstraction (e.g. emotions, social power, and time, to name a few) are grounded in particular domains of concrete experience (see, for example, Lakoff and Johnson's [1980] influential "conceptual metaphor" approach). As one example of this, a series of recent studies have demonstrated that the comprehension of language about time (e.g. shifts between the past and the future) is grounded in representations of the space around one's body (e.g. Santiago, Lupianez, Perez, and Fuenes, 2007; Ulrich *et al.*, 2012; Sell and Kaschak, 2011). Santiago *et al.* (2007) report that the understanding of past and future tense is grounded in the left-right axis (past = left, future = right). Sell and Kaschak (2011) report a different mapping of space and time (e.g. future is in front of you, past is behind you; see also Boroditsky and Ramscar, 2002). There is clearly more to understand with respect to how spatial representations are used to ground the comprehension of abstractions such as time, but these findings nonetheless provide evidence that the understanding of concrete domains of experience (e.g. moving in the space around one's body) provides a basis for understanding language about abstractions such as time.

Embodiment and language comprehension: criticisms and alternatives

Although the embodied approach to language comprehension (and to cognition in general) has received a growing amount of support in the literature, embodied approaches have not been without their critics. The critics, while acknowledging that there is an empirical case for claiming that perceptual and motor systems are activated during language processing, typically argue that the embodied hypothesis is incomplete, and that the sensorimotor representations invoked by embodiment theorists must be incorporated into a broader approach that contains both "embodied" and "abstract, symbolic" representations (e.g. Mahon and Caramazza, 2008; Louwerse, 2008).

Mahon and Caramazza (2008) presented a "grounding by interaction" view which posits that conceptual knowledge consists of both sensorimotor representations and abstract, symbolic

representations abstracted from experience. To borrow an example from their paper, consider the concept *dog*. We have sensorimotor experiences with specific dogs (e.g. retrievers and Dalmatians), but these experiences do not constitute the concept *dog*. Rather, the concept resides on an abstract layer of representation that generalizes across these experiences. Mahon and Caramazza (2008) further suggest that the extant literature on “embodiment” effects cannot distinguish between a view in which sensorimotor representations are directly activated as a function of linguistic input and a view in which linguistic input activates abstract, symbolic representations, sensorimotor representations, or both, and that activation rapidly cascades between the two types of representation.

We are sympathetic to Mahon and Caramazza’s (2008) view that our understanding of concepts such as *dog*, *violin*, or *beauty* is richer than what is encapsulated in the view of embodiment detailed throughout this chapter. However, given the deep and well-noted problems with abstract symbolic representational schemes (e.g. Barsalou, 1993; Harnad, 1990; Glenberg and Robertson, 2000), it is not clear to us that Mahon and Caramazza’s (2008) proposal represents a promising route forward. For example, they assert that there is no set of particular sensorimotor simulations that can capture all the meanings and uses of the word *beautiful*. This may be, but stipulating an ill-defined “abstract” layer of representation does not strike us as moving toward a workable solution.

Louwerse (2008; Louwerse and Connell, 2011) has similarly proposed a symbol interdependency hypothesis, which posits that linguistic meaning derives from both abstract, symbolic information (in this case, statistical co-occurrences between words) and sensorimotor representations. The symbolic, statistical information is presumed to be used early in the processing of language (providing a good-enough, surface-level interpretation of the linguistic input), and sensorimotor information is presumed to be used later in the processing of language (providing a more detailed representation of the content of the language). As above, we are sympathetic to the approach represented by this hypothesis; indeed, we feel that it is past time for embodied theories of language comprehension to be integrated more fully with the “statistical” or constraint-based approaches to sentence processing found in psycholinguistics (e.g. MacDonald, Pearlmutter, and Seidenberg, 1994). At the same time, it is not clear that the claims made by this approach are actually problematic for embodiment. One aspect of this account – that sensorimotor representations are accessed late in the comprehension process – is contradicted by the data. Pulvermüller (1999), Boulenger *et al.* (2006), and Bub and Masson (2010), among others, all show that motor activity occurs rapidly during online language processing. A second way in which this account is misguided is that it presumes that “statistical” information must necessarily be “abstract” or “symbolic,” and not embodied. This need not be the case, especially when one considers that the statistical information is essentially co-occurrences of perceptual and motoric events (e.g. speech production, hearing or reading words).

Embodiment and language comprehension: beyond sensorimotor simulations

We are skeptical that the hybrid embodied-symbolic accounts sketched in the preceding section will turn out, in the long run, to be viable theoretical accounts of language comprehension. Nonetheless, the criticism that the embodied approach to language comprehension is incomplete in its ability to explain the multiple facets of linguistic meaning has validity. Answering this criticism within the framework of an embodied perspective requires thinking of the embodiment of language in broader terms than equating embodiment with sensorimotor simulations.

The chapters in this volume discuss embodiment from a variety of perspectives, some sticking close to the “embodiment as simulation” view and others embracing an approach to embodiment that emphasizes the “situated” nature of cognition. In the former case, the focus is on how specific cognitive content is represented (e.g. what do we know about violins?). In the latter case, there is a focus on acting in the environment in a broader sense. Thinking about language in this way, we can consider that language comprehenders know things about the objects and actions that are described by language, and also about language as an act in and of itself. That is, we know about the physical act of speaking (or writing), and we know how to use these sequences of action to accomplish specific goals (e.g. speech acts; Austin, 1960).

Pickering and Garrod (2013) have recently explicated this idea by distinguishing between *embodiment in content* (i.e. simulations of the contents of language) and *embodiment in form* (i.e. knowledge of how language is produced, and the role that this plays in the production and comprehension of language). Just as we may understand others’ actions in terms of the possible actions of our own bodies (e.g. Rizzolatti, Sinigaglia, and Anderson, 2008), one component of our understanding of language may be our knowledge of how to physically produce language, and knowledge of patterns of speech that we have previously both heard and produced ourselves. In this way, information that is relevant to the interpretation of language, such as intonation contours, tone of voice, and the like, but outside of the purview of sensorimotor simulations (as they are normally construed), may still be seen as falling within the scope of an embodied account of language comprehension. When embodiment is considered from this broader perspective, we believe it will be possible to subsume the observations that Mahon and Caramazza (2008) and Louwerse and colleagues (e.g. Louwerse 2008) considered to be problematic for the simulation view of embodiment under a more expansive of this theoretical perspective.

References

- Austin, J. L. (1960). *How to do things with words*. Oxford: Oxford University Press.
- Barsalou, L. W. (1993). Flexibility, structure, and linguistic vagary in concepts: Manifestations of a compositional system of perceptual symbols. In A. C. Collins, S. E. Gathercole, and M. A. Conway (Eds.), *Theories of memory* (pp. 29–101). London: Lawrence Erlbaum Associates.
- (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, 22, 577–660.
- Bergen, B., Lindsay, S., Matlock, T., and Narayanan, S. (2007). Spatial and linguistic aspects of visual imagery in sentence comprehension. *Cognitive Science*, 31, 733–64.
- Binder, J. R., Desai, R. H., Graves, W. W., and Conant, L. L. (2009). Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cerebral Cortex*, 19, 2767–96.
- Boroditsky, L., and Ramscar, M. (2002). The roles of body and mind in abstract thought. *Psychological Science*, 13, 185–89.
- Borreggine, K. L., and Kaschak, M. P. (2006). The action–sentence compatibility effect: It’s all in the timing. *Cognitive Science*, 30, 1097–1112.
- Boulenger, V., Roy, A. C., Paulignan, Y., Deprez, V., Jeannerod, M., and Nazir, T. A. (2006). Cross-talk between language processes and overt motor behavior in the first 200 ms of processing. *Journal of Cognitive Neuroscience*, 18, 1607–15.
- Bub, D. N., and Masson, M. E. J. (2010). On the nature of hand-action representations evoked during written sentence comprehension. *Cognition*, 116, 394–408.
- Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., and Rizzolatti, G. (2005). Listening to action-related sentences modulates the activity of the motor system: A combined TMS and behavioral study. *Cognitive Brain Research*, 24, 355–63.
- Casasanto, D., and Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition*, 106, 579–93.
- de Vega, M., Glenberg, A. M., and Graesser, A. C. (Eds.) (2008). *Symbols, embodiment, and meaning*. Oxford: Oxford University Press.

- Engelhaaf, M., Kern, R., Krapp, H. G., Kretzberg, J., Kurtz, R., and Warzecha, A. K. (2002). Neural encoding of behaviorally relevant visual-motion information in the fly. *Trends in Neurosciences*, 25, 96–102.
- Fischer, M. H., and Zwaan, R. A. (2008). Embodied language—A review of the role of the motor system in language comprehension. *Quarterly Journal of Experimental Psychology*, 61, 825–50.
- Gibbs, R. W. (2011). Evaluating conceptual metaphor theory. *Discourse Processes*, 48, 529–62.
- Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences*, 20, 1–55.
- Glenberg, A. M., and Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, 9, 558–65.
- Glenberg, A. M., and Robertson, D. A. (2000). Symbol grounding and meaning: A comparison of high-dimensional and embodied theories of meaning. *Journal of Memory and Language*, 43, 379–401.
- Glenberg, A. M., Sato, M., Cattaneo, L., Riggio, L., Palumbo, D., and Buccino, G. (2008). Processing abstract language modulates motor system activity. *Quarterly Journal of Experimental Psychology*, 61, 905–19.
- Grabowsky, G. L. (1994). Symmetry, locomotion, and the evolution of the anterior end: A lesson from sea urchins. *Evolution*, 48, 1130–46.
- Harnad, S. (1990). The symbol grounding problem. *Physica D: Nonlinear Phenomena*, 42, 335–46.
- Hauk, O., Johnsrude, I., and Pulvermüller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron*, 41, 301–7.
- Havas, D. A., Glenberg, A. M., Gutowski, K. A., Lucarelli, M. J., and Davidson, R. J. (2010). Cosmetic use of botulinum toxin-A affects processing of emotional language. *Psychological Science*, 21, 895–900.
- Havas, D. A., Glenberg, A. M., and Rinck, M. (2007). Emotion simulation during language comprehension. *Psychonomic Bulletin & Review*, 14, 436–41.
- Kaschak, M. P., Madden, C. J., Theriault, D. J., Yaxley, R. H., Aveyard, M., Blanchard, A. A., et al. (2005). Perception of motion affects language processing. *Cognition*, 94, B79–89.
- Lakoff, G., and Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.
- Landauer, T. K., and Dumais, S. T. (1997). A solution to Plato’s problem: A latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychological Review*, 104, 211–40.
- Louwerse, M. (2008). Embodied relations are encoded in language. *Psychonomic Bulletin & Review*, 15, 838–44.
- Louwerse, M., and Connell, L. (2011). A taste of words: Linguistic context and perceptual simulation predict the modality of words. *Cognitive Science*, 35, 381–98.
- MacDonald, M. C., Pearlmutter, N. J., and Seidenberg, M. S. (1994). The lexical nature of syntactic ambiguity resolution. *Psychological Review*, 101, 676–703.
- MacIver, M. A. (2009). Neuroethology: From morphological computation to planning. In P. Robbins and M. Aydede (Eds.) *Cambridge handbook of situated cognition* (pp. 480–504). Cambridge: Cambridge University Press.
- Mahon, B. Z., and Caramazza, A. (2008). A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. *Journal of Physiology–Paris*, 102, 59–70.
- Martin, A. (2007). The representation of object concepts in the brain. *Annual Review of Psychology*, 58, 25–45.
- Masson, M., Bub, D., and Warren, C. (2008). Kicking calculators: Contribution of embodied representations to sentence comprehension. *Journal of Memory and Language*, 59, 256–65.
- Meteyard, L., Bahrami, B., and Vigliocco, G. (2007). Motion detection and motion words: Language affects low-level visual perception. *Psychological Science*, 18, 1007–13.
- Paulin, M. G. (2005). Evolutionary origins and principles of distributed neural computation for state estimation and movement control in vertebrates. *Complexity*, 10, 56–65.
- Pickering, M. J., and Garrod, S. (2013). An integrated theory of language production and comprehension. *Behavioral and Brain Sciences*, 36(4), 329–47.
- Pulvermüller, F. (1999). Words in the brain’s language. *Behavioral and Brain Sciences*, 22, 253–79.
- Richardson, D. C., and Matlock, T. (2007). The integration of figurative language and static depictions: An eye movement study of fictive motion. *Cognition*, 102, 129–38.
- Rizzolatti, G., Sinigaglia, C., and Anderson, F. (2008). *Mirrors in the brain: How our minds share actions and emotions*. Oxford: Oxford University Press.
- Santiago, J., Lupianez, J., Perez, E., and Fuenes, M. J. (2007). Time (also) flies from left to right. *Psychonomic Bulletin & Review*, 14, 512–16.
- Searle, J. (1980). Minds, brains, and computers. *Behavioral and Brain Sciences*, 3, 417–57.
- Sell, A. J., and Kaschak, M. P. (2011). Processing time shifts affects the execution of motor responses. *Brain and Language*, 117, 39–44.

- Stanfield, R. A., and Zwaan, R. A. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science*, 12, 153–56.
- Taylor, L. J., and Zwaan, R. A. (2008). Motor resonance and linguistic focus. *Quarterly Journal of Experimental Psychology*, 61, 896–904.
- Tettamanti, M., Buccino, G., Saccuman, M. C., et al. (2005). Listening to action-related sentences activates fronto-parietal motor circuits. *Journal of Cognitive Neuroscience*, 17, 273–81.
- Ulrich, R., Eikmeier, V., de la Vega, I., Rernandez, S. R., Alex-Ruf, S., and Maienborn, C. (2012). With the past behind and the future ahead: Back-to-front representation of past and future sentences. *Memory and Cognition*, 40, 483–95.
- Walsh, V. (2003). A theory of magnitude: Common cortical metrics of time, space, and quantity. *Trends in Cognitive Science*, 7, 483–88.
- Wolpert, D. M., Ghahramani, Z., and Flanagan, J. R. (2001). Perspectives and problems in motor learning. *Trends in Cognitive Sciences*, 5, 487–94.
- Zwaan, R. A., Madden, C. J., Yaxley, R. H., and Aveyard, M. E. (2004). Moving words: Dynamic mental representations in language comprehension. *Cognitive Science*, 28, 611–19.
- Zwaan, R. A., Stanfield, R. A., and Yaxley, R. H. (2002). Language comprehenders mentally represent the shape of objects. *Psychological Science*, 13, 168–71.
- Zwaan, R. A., and Taylor, L. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General*, 135, 1–11.

13

EMBODIMENT AND LANGUAGE

Claudia Scorolli

Embodied view of language

Embodied perspectives on concepts (e.g. Barsalou, 1999; Glenberg, 1997) emphasize that cognition is shaped by the physical properties of the world (i.e. “grounded”) in multiple ways (by simulations, or, occasionally, by bodily states); that our concepts are shaped by the physical constraints of our body (i.e. “embodied”); that cognitive processing strongly depends on current constraints and task demands (i.e. “situated”; see Pezzulo *et al.*, 2013). Behavioral and brain-imaging studies collected in the last few years converge in indicating that seeing an object activates motor information¹ (e.g. Tucker and Ellis, 1998; Ellis and Tucker, 2000; Grèzes, Tucker, Armony, Ellis, and Passingham, 2003). Importantly the physical context, i.e. the actual possibility of reaching the object (Costantini, Ambrosini, Scorolli, and Borghi, 2011; Ambrosini, Scorolli, Borghi, and Costantini, 2012), and the social context, i.e. the presence of another agent (virtual avatar: Costantini, Committeri, and Sinigaglia, 2011; or other person: Gianelli, Scorolli, and Borghi, 2013), seem to modulate this information.

Nevertheless not only the visual perception of an object, but also language processing elicits the involvement of the motor system. As words act as surrogates for more direct interactions with the environment (Glenberg, 1997), language processing recruits brain areas typically involved in perceiving objects and interacting with them. Across psychology, neuroscience and cognitive linguistics (see Bergen, 2005; Gibbs, 2003; Pecher and Zwaan, 2005), strong empirical evidence provides support for the view that language comprehension results in embodied representations² (Gallese and Goldman, 1998; Zwaan, 2004; Glenberg and Kaschak, 2002), that is in “simulations”. The notion of “simulation” is still a topic of debate, but there is general agreement in understanding it as the activation of the same sensorimotor neural correlates³ involved when we previously interacted with the referent of the word, i.e. the actual object (e.g. “apple”), or we executed the specific action described by the word (e.g. “grasping”) (Gallese 2008; Gallese and Sinigaglia, 2011).

The specificity of the simulation

Much recent evidence suggests that the mental simulation we run when comprehending language is not grounded in previous sensorimotor experience of a generic sort, but instead invokes rather specific sensorimotor experiences.

Object properties

Embodied simulations are sensitive to differences pertaining to intrinsic object properties (e.g. shape: Zwaan, Stanfield, and Yaxley, 2002; size: Glover and Dixon, 2002; Borghi and Riggio, 2009; color: Connell, 2007) as well as extrinsic⁴ ones (e.g. orientation: Stanfield and Zwaan, 2001; Borghi and Riggio, 2009; distance: Winter and Bergen, 2012), as shown by using the sentence-picture verification task.⁵ Participants read a sentence in which the shape/orientation/color of an object was implied (e.g. “John put the pencil in the cup” vs. “in the drawer”). Immediately after they were presented with an object’s picture that could match or mismatch the object’s property evoked by language (e.g. the pencil’s axis of symmetry in vertical vs. horizontal plane). They had to judge whether the shown object was mentioned in the sentence. Crucially the pictured object’s shape/orientation/color was irrelevant to the task. Nonetheless participants’ responses were modulated by the properties implied by the previous sentence, with a mismatch disadvantage⁶ (i.e. facilitation effect). Beyond the objects’ features, comprehenders seem to simulate also the direction of the objects’ motion (Zwaan, Madden, Yaxley, and Aveyard, 2004; Kaschak *et al.*, 2005): participants were faster in making judgments on sentences describing a motion in an opposite direction to the one shown by a simultaneously presented visual stimuli (i.e. interference effect). To disentangle facilitation and interference effects, two accounts have been proposed:⁷ temporal overlap (i.e. the relative timing of the perceptual stimulation and the conceptual task) and integratability (i.e. the extent to which the perceptual simulation can be integrated into the simulation constructed during language comprehension).

Furthermore concepts seem to be represented by modality-specific sensory-motor systems (Barsalou, Pecher, Zeelenberg, Simmons, and Hamann, 2005); therefore the described simulation processing does not involve only the visual modality, but also, for example, the auditory one⁸ (Pecher, Zeelenberg, and Barsalou, 2003).

Relational properties

As conceptual knowledge guides action in the world, the simulations activated by language processing do not imply only perceptual details (e.g. visual or auditory simulations), but also motor ones. They involve the specific static or dynamic relation between the agent and the objects, as their relative positions, or the kind of interaction. Using a part verification task Borghi, Glenberg, and Kaschak (2004) found that response latencies were affected by the perspective (inside vs. outside) induced by language (e.g. “You are eating in a restaurant”: advantage for “table”; “You are waiting outside a restaurant”: advantage for “sign”). Varying participants’ motor responses (upward vs. downward movement) they also found an advantage for responses’ direction compatible with the object part’s typical location (e.g. responding upward to verify that “a doll” does have “hair”).

Still manipulating the actions required to perform the task, Glenberg and Kaschak (2002) directly tested if the comprehension of sentences referring to oppositely directed actions affected response times.⁹ Even if they were never instructed to consider the direction implied by the sentence, participants were faster and more accurate in judging the sensibility of sentences when there was a match between the movement direction implied by the sentence (e.g. “Put your finger under your nose” vs. “under the faucet”) and the one required to respond (button near vs. far from the body) rather than in the case of mismatch. This *action-sentence compatibility effect* further supports the embodied claim that language understanding is grounded in bodily action (see Table 13.1).

Table 13.1 Examples of evidence on the specificity of simulation activated by language understanding.

Referential aspect of language: Specificity of the simulation activated by concrete language					
Semantic features			Grammatical categories and constructions		
Object properties		Relational properties		What part of the event to focus on	
Intrinsic object features	Extrinsic object features	Direction of object motion	Perspectives	Action	Kind of effector (mouth, foot); specific effector (right, left hand)
SHAPE Zwaan <i>et al.</i> , 2002 SIZE Glover and Dixon, 2002; Borghini and Riggio, 2009 COLOR Connell, 2007 MASS Scorolli <i>et al.</i> , 2009; Scorolli, 2011	ORIENTATION Stanfield and Zwaan, 2001; Borghini and Riggio, 2009 DISTANCE Winter and Bergen, 2012	Zwaan <i>et al.</i> , 2004; Kaschak <i>et al.</i> , 2005	Borghini <i>et al.</i> , 2004; Brunyé <i>et al.</i> , 2009; Sato and Bergen, 2013 SOCIAL PERSPECTIVE Gianelli <i>et al.</i> , 2013	Glenberg and Kaschak, 2002; Glenberg <i>et al.</i> , 2008; Bergen and Wheeler, 2010	Pulvermüller <i>et al.</i> , 2001; Buccino <i>et al.</i> , 2005; Scorolli and Borghi, 2007; Borghi and Scorolli, 2009; Kemmerer and Castillo, 2010
				Agent > Pronoun	Action > Adverb, verb
					Object > Adjective, noun
				Brunyé <i>et al.</i> , 2009; Sato and Bergen, 2013	ADJECTIVE vs. ADVERB Gentilucci <i>et al.</i> , 2000 ADJECTIVE vs. VERB Gentilucci, 2003; Madden and Zwaan, 2003; Kemmerer and Castillo, 2010; Bergen and Wheeler, 2010

The effector and the final goal

The semantics of verbs does not imply only a specific direction of action (e.g. “opening” vs. “closing”) but also a specific part of the agent’s body (e.g. “grasping” vs. “kicking”), and possibly a specific final goal (e.g. “grasping the toffee to eat it” vs. “grasping the aubergine to cook it”). In order to further investigate the kind of relationship existing between language and the motor system recent studies used single verbs (Pulvermüller, Härle, and Hummel, 2001; Buccino *et al.*, 2005), or verbs embedded in sentences (Scorolli and Borghi, 2007; Borghi and Scorolli, 2009), that could refer to hand-arm/foot-leg/mouth actions (see Table 13.1). Depending on the methodology used, response latencies from different effectors (behavioral paradigms) or event-related current source densities from brain electrical activity (electroencephalography, EEG) and motor-evoked potentials from hand muscles (transcranial magnetic stimulation, TMS) were collected. Neurophysiological data converged in demonstrating that action words elicit neurophysiological activity with different cortical topographies (e.g. Pulvermüller *et al.*, 2001; Buccino *et al.*, 2005), reflecting the words’ meanings. Consistently, behavioral findings (e.g. Buccino *et al.*, 2005; Scorolli and Borghi, 2007) highlighted a modulation determined by the match or mismatch¹⁰ between the specific effector referred to by language and the one used to respond (e.g. sentences: “to throw the ball” vs. “to kick the ball”; response-effector: hand vs. foot).

Finally, action words seem to be represented and encoded not just at a proximal level but also at a distal level (see Hommel, Müsseler, Aschersleben, and Prinz, 2001), as the simulation entailed by language processing is sensitive also to the final goal expressed by the sentence. Coherently Borghi and Scorolli (2009) found an advantage for verb-noun pairs referring to manual actions (e.g. “to pick up – grapes”) and mouth actions (e.g. “to eat – grapes”), but not for pairs referring to foot actions (e.g. “to press – grapes”) in case of dominant-right-hand responses. This effect is consistent with the fact that usually an action with the mouth (e.g. eating a slice of bread), but not with the foot, implied a previous action with the hand (e.g. slicing the bread and bringing it to the mouth); it is also consistent with evidence indicating that at the neural level hand and mouth actions activate contiguous regions (e.g. Pulvermüller *et al.*, 2001). It is worth noting that these findings support striking proposals suggesting that language could have evolved from gestures (e.g. Corballis, 2002; Arbib, 2005).

Grammatical features

The reviewed evidence suggests that the simulation triggered by language is affected by content words, like nouns and verbs. Nonetheless another aspect to be considered is whether, and possibly how, grammar affects language-driven mental simulations. The meaning of noun/verb specifies which kind of object/action to simulate, i.e. their properties. However, given a scene to be simulated, it is important to identify also higher-order characteristics of simulation (see Glenberg and Gallese, 2012; Sato, Schafer, and Bergen, 2013; see Table 13.1): grammar serves this important function. Bergen and Wheeler (2010) found that progressive aspect drives comprehenders to mentally simulate the central process of a described motor event, while perfect aspect does not. These effects (“second-order effects” of grammar) are qualitatively different from the effects of content words, as grammatical aspect markers operate over the representations evoked by content words, for example modulating the specific part of simulation on which to focus (e.g. “Virginia is brushing her teeth” vs. “Virginia has brushed her teeth”: progressive aspects accentuate the internal structure of an event, while perfect aspects highlight the resulting end state, see Dowty, 1977).

The issue of abstractness

The evidence above strongly supports the main claim of standard embodied accounts: concepts are grounded in perception and action systems, and therefore they are modal. However, all these

empirical studies focus on words with concrete referents (e.g. highly imageable words), and have limited reach with respect to abstract concepts (Louwerse and Jeuniaux, 2010; Borghi and Cimatti, 2009; 2012; Dove, 2009; Mahon and Caramazza, 2008). While many studies have been devoted to this important topic, the issue of abstractness remains puzzling (for a recent review, see Pecher, Boot, and van Dantzig, 2011; see also the special issues edited by Scorolli, 2012, and by Borghi and Pecher, 2012).

Some studies show that abstract words refer metaphorically to concrete referents (Lakoff and Johnson, 1999; Casasanto and Boroditsky, 2008), that abstract sentences recruit the motor system (Glenberg *et al.*, 2008; see also Glenberg and Gallese, 2012) and that abstract concepts elicit situations, as well as simulations of internal states (Barsalou and Wiemer-Hastings, 2005). This research, though compelling, refers only to a limited subset of phenomena (see Borghi and Cimatti, 2009).

In an effort to generalize these results, a first step could be to study the abstract-concrete dimension in a continuum (Wiemer-Hastings, Krug, and Xu, 2001). In a recent cross-cultural study Scorolli, Binkofski, *et al.* (2011) combined the same concrete verb (action-related verb, e.g. “to grasp”) with a concrete noun (graspable object, e.g. “a flower”) and with an abstract noun (non-graspable object, e.g. “a concept”), and then an abstract verb (verb not directly related to action, e.g. “to describe”) with the nouns previously used. Participants had to evaluate sensibility of the combinations. To take into account also grammatical features, two syntactically different languages were considered: German and Italian (in the former the nouns precede the verbs). Compatible combinations (concrete-concrete, abstract-abstract) were processed faster than mixed ones, and did not differ, whereas processing of mixed combinations (concrete-abstract, abstract-concrete) was modulated by the specific language: when concrete words preceded abstract ones responses were faster (regardless of the word grammatical class). Results on compatible combinations can be explained by modal theories, but also by amodal ones. Conversely findings from the mixed combinations are consistent with the claim that both abstract and concrete words are represented modally, and they activate parallel systems: one relying more on perception and action areas, the other more on sensorimotor linguistic areas (switching between systems implies a cost: Pecher *et al.*, 2003). The higher difficulty of abstract words could reflect their later acquisition (Borghi and Cimatti, 2009, 2012), given that linguistic experience is particularly relevant for concrete words.

The same paradigm was used also in studies involving both TMS (Scorolli, Jacquet, *et al.*, 2012) and fMRI (functional magnetic resonance: Sakreida *et al.*, 2013). They converged in showing that both concrete and abstract multiword expressions engage core areas of the sensorimotor neural network (Scorolli, Jacquet, *et al.*, 2012; Sakreida *et al.*, 2013). But while phrases containing concrete verbs imply a direct early activation of the hand-related motor system, the activation of the same system is delayed in the case of phrases containing abstract verbs (Scorolli, Jacquet, *et al.*, 2012): the processing of abstract verbs could first engage mouth-related motor areas, that later affect the contiguous areas (hand areas). Furthermore, processing of abstract noun-abstract verb combinations compared with concrete language content shows a pronounced activation in the left anterior middle temporal gyrus (Sakreida *et al.*, 2013), an area close to the language-processing system (see Price, 2010).

Multiple types of representations

How to explain these results? Attempts to sketch a framework to address both concrete and abstract words representation suggest that multiple representational systems¹¹ are activated during conceptual processing. Some of these proposals adopt an embodied perspective¹² and do not

assume a transduction process from sensorimotor experience to abstract-amodal symbols. Barsalou, Santos, Simmons, and Wilson (2008) have proposed the Language And Situated Simulation theory (LASS), claiming that linguistic forms and situated simulations interact continuously: different mixtures of the two systems underlie a wide variety of tasks. The linguistic system (left-hemisphere) is involved mainly during superficial linguistic processing, whereas deeper conceptual processing requires the activation of the sensorimotor system (bilateral posterior areas). In a similar vein, Borghi and Cimatti (2009, 2012; Words As Tools theory, WAT) propose to extend the embodied view of cognition in order to consider not only language grounding but also the role that language plays in shaping our experience. In contrast to LASS, WAT claims that the linguistic system does not simply involve a form of superficial processing. WAT makes specific predictions concerning abstract and concrete word representations: while both engage the sensorimotor neural network (Scorolli, Jacquet, *et al.*, 2012; Sakreida *et al.*, 2013), abstract words specifically activate the linguistic neural network. *Why?* According to the authors the reason is to be found in the different acquisition mechanisms for concrete and abstract words (Borghi and Cimatti, 2009, 2012).

The acquisition of new words

In acquiring concrete words, we first experience the concrete entities (e.g. pencil), and then we tag them using linguistic labels (we learn the name “pencil”). With abstract words, we might initially learn a word (the label) and then “tag” it with our sensorimotor experience, that is we use the word to assemble a set of experiences (e.g. we probably put together different experiences of freedom once we have learned the word “freedom”). Therefore abstract words refer to more varied experiences than concrete words, and language might be necessary to keep all these (bodily) experiences together. Consistently general abstract word meanings rely more than concrete word meanings on the social experience of language. The novelty of this proposal basically consists in conceiving words not as mere signals of something, but also as “social tools” (Borghi and Cimatti, 2009, 2012).

If the core difference between concrete and abstract words is to be found in their peculiar acquisition mechanisms,¹³ simulating the acquisition of new concrete and abstract words should lead to findings symmetrical to the ones obtained with existing words. With the aim to verify this prediction Borghi and colleagues (Borghi, Flumini, Cimatti, Marocco, and Scorolli, 2011) performed four experiments in which they simulated the acquisition of new words. First, participants acquired new concepts by manipulating novel objects (concrete concepts) or by observing groups of objects interacting in novel ways (abstract concepts). Then they were provided with a new category label for each concept. To assess if the novel abstract and concrete words actually differed along the same dimensions as existing abstract and concrete ones, participants performed a feature production task, in which they were asked to list properties for each concept-label. Crucially the association score analyses showed that concrete words evoked more perceptual properties, as typically found with existing concrete words (Borghi and Caramelli, 2001). Participants were also asked to judge which one of two exemplars corresponded to a given (previously learnt) verbal label. Results on errors showed that it was more difficult to form abstract than concrete categories. Finally participants performed a color verification task (on the experienced objects / groups of objects) with manual or verbal responses. Interestingly, for abstract words microphone use was easier than keyboard use; symmetrical results were found for concrete words. Consistently with the predictions, (new) concrete words evoked more manual information, while (new) abstract words elicited more verbal information (Borghi and Cimatti, 2009; for similar results see also Scorolli, Granito, and Borghi, 2013).

New perspectives on language: language to act

Cultural and social features

As we have seen, a critical problem embodied views face concerns the issue of how abstract words are represented. According to recent proposals, both sensorimotor and linguistic information play a role in conceptual representation (Barsalou *et al.*, 2008; Borghi and Cimatti, 2009, 2010). The WAT proposal advances the idea that language is not only affected by our previous experience, but it also actively shapes speakers' perceptions of the world (see also Boroditsky and Ramscar, 2002; Gentner, 2003; compare the Whorfian hypothesis: Whorf, 1956).

In keeping with this hypothesis, some recent evidence suggests that different languages can differently carve up our experience. For example, in the behavioral study, Scorolli, Binkofski, *et al.* (2011) found differences between speakers of two languages that differ grammatically: German participants were faster with abstract verbs while Italian ones were slower with the same kind of verbs (regardless of the kind of noun that preceded or followed the verb). In a similar vein, Bergen and Chan Lau (2012) tested native speakers of English, Mandarin Chinese from mainland China, and Mandarin Chinese from Taiwan: the writing direction for the first two groups is left to right and then top to bottom; for the third group, writing direction is predominantly top to bottom and then right to left. When asked to order cards describing different stages of temporal development, participants basically replicated differences in the native writing systems, supporting the idea that the axis used to represent time in terms of space is affected by language experience. In a related study Siyanova-Chanturia, Pesciarelli, and Cacciari (2012) tested people belonging to the same culture (Italian) to verify if gender stereotypes conveyed by language affected the processing of third-person pronouns. Results on event-related brain potentials confirmed their hypothesis; importantly they also found that female (e.g. teacher) and male (e.g. driver) stereotypes affected the processing of pronouns differently.

The attention on the *social* aspects of language has suggested a focus on not only cultural differences,¹⁴ but also on the effects of having another person in the scene (Knoblich and Sebanz, 2008; Goldman and de Vignemont, 2009), with or without a collaborative attitude (see Tomasello, 2009; Scorolli, Miatton, Wheaton, and Borghi, 2012; Becchio *et al.*, 2012). Gianelli, Scorolli, and Borghi (2013) investigated whether the reach-to-grasp movement towards an object was influenced by the presence of a second person. This person could be either a friend or a non-friend, and was either invisible (behind) or located in different positions with respect to the agent and to the object. While only the agent performed the physical action, both the participants could be (in turn) the speaker. Before movement initiation, the speaker pronounced a sentence referring to her own action (e.g. “I grasp”) or to the same action performed by the other (e.g. “You grasp”). Interestingly, the agent's grasping component of the movement was influenced by the kind of relationship between her and the other person, as well as by the relative physical position. Most crucially, the overall reaching time showed an interaction between the speaker and the used pronoun: participants reached for the object more quickly when the other spoke, particularly if she used the “I” pronoun.

This evidence supports the idea of two forms of *social perspective*: the physical perspective, conveyed by both the other's body position and the distance from the object, and the perspective induced by language. Speaking, and particularly assuming the first-person perspective (linguistically conveyed by the first-person pronoun), evokes a potential action, consistently with the claim that words can be intended as kinds of actions. In a similar vein, Scorolli and co-authors (Scorolli, Daprati, Nico, and Borghi, 2011) showed that effective use of words, like

an effective use of physical external auxiliaries such as tools (e.g. Farnè, Iriki, and Làdavas, 2005), can determine an extension of the peripersonal space (Borghi and Cimatti, 2009; 2010; Clark, 2008).

Extended mind

Nowadays we badly need further evidence to complement this big picture,¹⁵ particularly empirical data on normal language development¹⁶ (see Bergelson and Swingley, 2013) as well as on developmental disorders (for a good review see Marcus and Rabagliati, 2006).

Nevertheless evidence collected so far clearly argues in favor of (1) a mind that is not “brainbound” (e.g. Clark, 2008; Noë, 2009; Wilson and Golonka, 2013), but distributed also beyond body’s edges; (2) a language that cannot be conceived only in its referential aspects, but also in its social and public features (e.g. Borghi and Cimatti, 2009); (3) body edges that are not static, but that can be plastically rearranged (e.g. Tsakiris, 2010; Longo and Serino, 2012). This suggests that an embodied-grounded view of cognition should be integrated with the extended mind view¹⁷ (Clark and Chalmers, 1998): the combination of these two perspectives promises to shed new light not only on language processing, but also on the actual potentialities of language (Borghi, Scorolli, Caligiore, Baldassarre, and Tummolini, 2013).

Notes

- 1 See Chapter 4 on “Complex Dynamical System and Embodiment”, by Michael J. Richardson and Anthony Chemero.
- 2 For an alternative perspective see also Tomasino and Rumati, 2013.
- 3 As to “Neuroscientific Bases of Embodiment”, see Chapter 5, by Laila Craighero.
- 4 I.e. properties that depend on object’s relationship with the agent and/or other objects.
- 5 For recent replication studies see Zwaan and Pecher, 2012.
- 6 For controversial results as to color see Zwaan and Pecher, 2012.
- 7 For a detailed discussion on interference and facilitation effects see Borreggine and Kaschak, 2006; Connell and Lynott, 2012.
- 8 It is worth noting that both modalities seem to use similar metrics, as found (2012) by contrasting the visual modality (e.g. “You are looking at the milk bottle across the supermarket” vs. “You are looking at the milk bottle in the fridge”) with the auditory one (e.g. “Someone fires a handgun in the distance” vs. “Right next to you, someone fires a handgun”: Winter and Bergen, 2012).
- 9 For studies measuring also kinematic parameters of the motor responses see for example Gentilucci *et al.*, 2000; Gentilucci, 2003; Scorolli, Borghi, and Glenberg, 2009.
- 10 For a discussion on embodied models explaining interference and facilitation effects see Borghi, Caligiore, and Scorolli, 2010; Borghi, Gianelli, and Scorolli, 2010.
- 11 See also the dual-coding theory, Paivio, 1986.
- 12 For a non-embodied version of this view see Dove, 2009.
- 13 For a close examination of the mode of acquisition construct see Wauters, Tellings, van Bon, and van Haften, 2003; as to “Concepts Acquisition”, see also Chapter 11, by Daniel Casasanto.
- 14 For an in-depth discussion, see the Chapter 20 on “Cultural Differences”, by Tamer Soliman and Art Glenberg.
- 15 See Chapter 35 on “Future Prospects”, by Michael Wheeler.
- 16 See Chapter 14 on “Language Acquisition”, by Chen Yu.
- 17 See Chapter 3, on “Extended Cognition”, by Ken Aizawa.

References

- Ambrosini, E., Scorolli, C., Borghi, A. M., and Costantini, M. (2012). Which body for embodied cognition? Affordance and language within actual and perceived reaching space. *Consciousness and Cognition*, 21, 1551–57.

- Arbib, M. A. (2005). From monkey-like action recognition to human language: An evolutionary framework for neurolinguistics. *Behavioral and Brain Sciences*, 28, 105–24.
- Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, 22, 577–609.
- Barsalou, L. W., Pecher, D., Zeelenberg, R., Simmons, W. K., and Hamann, S. B. (2005). Multi-modal simulation in conceptual processing. In W. Ahn, R. Goldstone, B. Love, A. Markman, and P. Wolff (Eds.), *Categorization inside and outside the lab: A festschrift in honor of Douglas L. Medin*. Washington, DC: American Psychological Association.
- Barsalou, L. W., Santos, A., Simmons, W. K., and Wilson, C. D. (2008). Language and simulation in conceptual processing. In M. De Vega, A. M. Glenberg, and A. C. Graesser (Eds.), *Symbols, embodiment, and meaning* (pp. 245–84). Oxford: Oxford University Press.
- Barsalou, L. W., and Wiemer-Hastings, K. (2005). Situating abstract concepts. In D. Pecher and R. Zwaan (Eds.), *Grounding cognition: The role of perception and action in memory, language, and thought* (pp. 129–63). New York: Cambridge University Press.
- Becchio, C., Cavallo, A., Begliomini, C., Sartori, L., Feltrin, G., and Castiello, U. (2012). Social grasping: From mirroring to mentalizing. *Neuroimage*, 61, 240–48.
- Bergelson, E., and Swingle, D. (2013) The acquisition of abstract words by young infants. *Cognition*, 127, 391–97.
- Bergen, B. K. (2005). Experimental methods for simulation semantics. In M. Gonzalez-Marquez, I. Mittelberg, S. Coulson, and M. J. Spivey (Eds.), *Methods in cognitive linguistics*. Amsterdam: John Benjamins.
- Bergen, B. K., and Chan Lau, T. T. (2012). Writing direction affects how people map space onto time. *Frontiers in Psychology*, 3(109).
- Bergen, B. K., and Wheeler, K. (2010). Grammatical aspect and mental simulation. *Brain and Language*, 112, 150–58.
- Borghi, A. M., Caligiore, D., and Scorolli, C. (2010). Objects, words, and actions: Some reasons why embodied models are badly needed in cognitive psychology. In V. Capecchi, M. Buscema, P. Contucci, and B. D’Amore (Eds.), *Applications of mathematics in models, artificial neural networks and arts: Mathematics and society*. Berlin: Springer.
- Borghi, A. M., and Caramelli, N. (2001). Taxonomic relations and cognitive economy in conceptual organization. In J. D. Moore and K. Stenning (Eds.), *Proceedings of 23rd Meeting of the Cognitive Science Society* (pp. 98–103). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Borghi, A. M., and Cimatti, F. (2009). Words as tools and the problem of abstract words meanings. In N. Taatgen and H. van Rijn (Eds.), *Proceedings of the 31st Annual Conference of the Cognitive Science Society* (pp. 2304–9). Amsterdam: Cognitive Science Society.
- (2010). Embodied cognition and beyond: Acting and sensing the body. *Neuropsychologia*, 48, 763–73.
- (2012). Words are not just words: The social acquisition of abstract words. *RIFL–Italian Journal of Philosophy of Language*, 5, 22–37 (ISSN 2036–6728).
- Borghi, A. M., Flumini, A., Cimatti, F., Marocco, D., and Scorolli, C. (2011). Manipulating objects and telling words: A study on concrete and abstract words acquisition. *Frontiers in Psychology*, 2(15).
- Borghi, A. M., Gianelli, C., and Scorolli, C. (2010). Sentence comprehension: Effectors and goals, self and others; an overview of experiments and implications for robotics. *Frontiers in neurorobotics*, 4(3).
- Borghi, A. M., Glenberg, A. M., and Kaschak, M. P. (2004). Putting words in perspective. *Memory and Cognition*, 32, 863–73.
- Borghi, A. M., and Pecher, D. (Eds.). (2012). Special topic on embodied and grounded cognition. Lausanne: Frontiers.
- Borghi, A. M., and Riggio, L. (2009). Sentence comprehension and simulation of object temporary, canonical and stable affordances. *Brain Research*, 1253, 117–28.
- Borghi, A. M., and Scorolli, C. (2009). Language comprehension and hand motion simulation. *Human Movement Science*, 28, 12–27.
- Borghi, A. M., Scorolli, C., Caligiore, D., Baldassarre, G., and Tummolini, L. (2013). The embodied mind extended: Using words as social tools. *Frontiers in Psychology*, 4(214).
- Boroditsky, L., and Ramscar, M. (2002). The roles of body and mind in abstract thought. *Psychological Science*, 13, 185–88.
- Borreggine, K. L., and Kaschak, M. (2006). The action-sentence compatibility effect: It’s all in the timing. *Cognitive Science*, 30, 1097–1112.
- Brunyé, T. T., Ditman, T., Mahoney, C. R., Augustyn, J. S., and Taylor, H. A. (2009). When you and I share perspectives: Pronouns modulate perspective taking during narrative comprehension. *Psychological Science*, 20, 27–32.

- Buccino, G., Riggio, L., Melli, G., Binkofski, F., Gallese, V., and Rizzolatti, G. (2005) Listening to action-related sentences modulates the activity of the motor system: A combined TMS and behavioral study. *Cognitive Brain Research*, 24, 355–63.
- Casasanto, D., and Boroditsky, L. (2008). Time in the mind: Using space to think about time. *Cognition*, 106, 579–93.
- Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. Oxford: Oxford University Press.
- Clark, A., and Chalmers, D. (1998). The extended mind. *Analysis*, 58, 7–19.
- Connell, L. (2007). Representing object colour in language comprehension. *Cognition*, 102, 476–85.
- Connell, L., and Lynott, D. (2012). When does perception facilitate or interfere with conceptual processing? The effect of attentional modulation. *Frontiers in Psychology*, 3(474).
- Corballis, M. C. (2002). *From hand to mouth: The origins of language*. Princeton: Princeton University Press.
- Costantini, M., Ambrosini, E., Scorolli, C., and Borghi, A. (2011). When objects are close to me: Affordances in the peripersonal space. *Psychonomic Bulletin & Review*, 18, 32–38.
- Costantini, M., Committeri, G., and Sinigaglia, C. (2011). Ready both to your and to my hands: Mapping the action space of others. *PLoS One*, 6, e17923.
- Dove, G. (2009). Beyond perceptual symbols: A call for representational pluralism. *Cognition*, 110, 412–31.
- Dowty, D. (1977). Toward a semantic analysis of verb aspect and the English “imperfective” progressive. *Linguistics and Philosophy*, 1, 45–77.
- Ellis, R., and Tucker, M. (2000). Micro-affordance: The potentiation of components of action by seen objects. *British Journal of Psychology*, 91, 451–71.
- Farnè, A., Iriki, A., and Ladavas, E. (2005). Shaping multisensory action-space with tools: Evidence from patients with cross-modal extinction. *Neuropsychologia*, 43, 238–48.
- Gallese, V. (2008) Mirror neurons and the social nature of language: The neural exploitation hypothesis. *Social Neuroscience*, 3, 317–33.
- Gallese, V., and Goldman, A. (1998). Mirror neurons and the simulation theory of mind-reading. *Trends in Cognitive Sciences*, 12, 493–501.
- Gallese, V., and Sinigaglia, C. (2011). What is so special with embodied simulation. *Trends in Cognitive Sciences*, 15, 512–19.
- Gentilucci, M. (2003). Object motor representation and language. *Experimental Brain Research*, 153, 260–65.
- Gentilucci, M., Benussi, F., Bertolani, L., Daprati, E., and Gangitano, M. (2000). Language and motor control. *Experimental Brain Research*, 133, 468–90.
- Gentner, D. (2003). Why we’re so smart. In D. Gentner and S. Goldin-Meadow (Eds.), *Language in mind: Advances in the study of language and cognition* (pp. 195–236). Cambridge, MA: MIT Press.
- Gianelli, C., Scorolli, C., and Borghi, A. M. (2013). Acting in perspective: The role of body and language as social tools. *Psychological Research*, 77, 40–52.
- Gibbs, R. W. (2003). Embodied experience and linguistic meaning. *Brain and Language*, 84, 1–15.
- Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences*, 20, 1–55.
- Glenberg, A. M., and Gallese, V. (2012). Action-based language: A theory of language acquisition, comprehension, and production. *Cortex*, 48, 905–22.
- Glenberg, A. M., and Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, 9, 558–65.
- Glenberg, A. M., Sato, M., Cattaneo, L., Riggio, L., Palumbo, D., and Buccino, G. (2008). Processing abstract language modulates motor system activity. *Quarterly Journal of Experimental Psychology*, 61, 905–19.
- Glover, S., and Dixon, P. (2002). Semantics affects the planning but not the control of grasping. *Experimental Brain Research*, 146, 383–87.
- Goldman, A. I., and de Vignemont, F. (2009). Is social cognition embodied? *Trends in Cognitive Sciences*, 13, 154–59.
- Grèzes, J., Tucker, M., Armony, J., Ellis, R., and Passingham, R. E. (2003). Objects automatically potentiate action: An fMRI study of implicit processing. *European Journal of Neuroscience*, 17, 2735–40.
- Hommel, B., Müsseler, J., Aschersleben, G., and Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences*, 24, 849–78.
- Kaschak, M. P., Madden, C. J., Theriault, D. J., Yaxley, R. J., Aveyard, M., Blanchard, A. A., and Zwaan, R. A. (2005). Perception of motion affects language processing. *Cognition*, 94, 79–89.
- Kemmerer, D., and Gonzalez Castillo, J. (2010). The two-level theory of verb meaning: An approach to integrating the semantics of action with the mirror neuron system. *Brain and Language*, 112, 54–76.

- Knoblich, G., and Sebanz, N. (2008). Evolving intentions for social interaction: From entrainment to joint action. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363, 2021–31.
- Lakoff, G., and Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to Western thought*. New York: Basic Books
- Longo, M. R., and Serino, A. (2012). Tool use induces complex and flexible plasticity of human body representations [commentary on Vaesen, K.]. *Behavioral Brain Sciences*, 35, 229–30.
- Louwerse, M. M., and Jeuniaux, P. (2010). The linguistic and embodied nature of conceptual processing. *Cognition*, 114, 96–104.
- Madden, C. J., and Zwaan, R. A. (2003). How does verb aspect constrain event representations? *Memory and Cognition*, 31, 663–72.
- Mahon, B. Z., and Caramazza, A. (2008). A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. *Journal of Physiology–Paris*, 102, 59–70.
- Marcus, G. F., and Rabagliati, H. (2006). What developmental disorders can tell us about the nature and origins of language. *Nature Neuroscience*, 9, 1226–29.
- Noë, A. (2009). *Out of our heads: Why you are not your brain, and other lessons from the biology of consciousness*. New York: Hill & Wang.
- Paivio, A. (1986). *Mental representations: A dual coding approach*. New York: Oxford University Press.
- Pecher, D., Boot, I., and van Dantzig, S. (2011). Abstract concepts: Sensory-motor grounding, metaphors, and beyond. In B. Ross (Ed.), *The psychology of learning and motivation* (Vol. 54, pp. 217–48). Burlington: Academic Press.
- Pecher, D., Zeelenberg, R., and Barsalou, L. W. (2003). Verifying different-modality properties for concepts produces switching costs. *Psychological Science*, 14, 119–24.
- Pecher, D., and Zwaan, R. A. (2005). *Grounding cognition: The role of perception and action in memory, language, and thinking*. Cambridge: Cambridge University Press.
- Pezzulo, G., Barsalou, L. W., Cangelosi, A., Fischer, M. H., McRae, K., and Spivey, M. J. (2013). Computational grounded cognition: A new alliance between grounded cognition and computational modeling. *Frontiers in Psychology*, 3(612).
- Price, C. J. (2010). The anatomy of language: A review of 100 fMRI studies published in 2009. *Annals of the New York Academy of Sciences*, 1191, 62–88.
- Prinz, J. J. (2002). *Furnishing the mind: Concepts and their perceptual basis*. Cambridge, MA: MIT Press.
- Pulvermüller, F., Härle, M., and Hummel, F. (2001). Walking or talking? Behavioral and electrophysiological correlates of action verb processing. *Brain and Language*, 78, 143–68.
- Sakreida, K., Scorolli, C., Menz, M. M., Heim, S., Borghi, A. M., and Binkofski, F. (2013). Are abstract action words embodied? An fMRI investigation at the interface between language and motor cognition. *Frontiers in Human Neurosciences*, 7(125).
- Sato, M., and Bergen, B. (2013). The case of the missing pronouns: Does mentally simulated perspective play a functional role in the comprehension of person? *Cognition*, 127, 361–74.
- Sato, M., Schafer, A., and Bergen, B. (2013). One word at a time: Mental representations of object shape change incrementally during sentence processing. *Language and Cognition*, 5, 345–73.
- Scorolli, C. (2011). Our words have a weight: Motor and perceptual resonance through language grounding. In R. K. Mishra and N. Srinivasan (Eds.), *Language-cognition interface: State of the art* (pp. 136–57). Munich: Lincom Europa.
- (Ed.) (2012). Special Topic on Action, Perception and Language. *RIFL–Italian Journal of Philosophy of Language*, 5 (ISSN 2036–6728). <http://www.rifl.unical.it/index.php/rifl/issue/view/8/showToc>
- Scorolli, C., Binkofski, F., Buccino, G., Nicoletti, R., Riggio, L., and Borghi, A. M. (2011). Abstract and concrete sentences, embodiment, and languages. *Frontiers in Psychology*, 2(227).
- Scorolli, C., and Borghi, A. M. (2007). Sentence comprehension and action: Effector specific modulation of the motor system. *Brain Research*, 1130, 119–24.
- Scorolli, C., Borghi, A. M., and Glenberg, A. (2009). Language-induced motor activity in bi-manual object lifting. *Experimental Brain Research*, 193, 43–53.
- Scorolli, C., Daprati, E., Nico, D., and Borghi, A. M. (2011). Catching objects through words. *Proceedings of the 17th Meeting of the European Society for Cognitive Psychology*, 46.
- Scorolli, C., Granito, C., and Borghi, A. M. (2013). Learning abstract words: The key brick of language. Conference on Embodied and Situated Language Processing, Potsdam.
- Scorolli, C., Jacquet, P. O., Binkofski, F., Nicoletti, R., Tessari, A., and Borghi, A. M. (2012). Abstract and concrete phrases processing differentially modulates cortico-spinal excitability. *Brain Research*, 1488, 60–71.

- Scorolli, C., Miatton, M., Wheaton, L. A., and Borghi, A. M. (2012). When a glass calls: Anatomy of a toast. *Cognitive Processing*, 13, S69–70.
- Siyanova-Chanturia, A., Pesciarelli, F., and Cacciari, C. (2012). The electrophysiological underpinnings of processing gender stereotypes in language. *PLoS One*, 7, e48712.
- Stanfield, R. A., and Zwaan, R. A. (2001). The effect of implied orientation derived from verbal context on picture recognition. *Psychological Science*, 121, 153–56.
- Tomasello, M. (2009). *Why we cooperate*. Cambridge, MA: MIT Press.
- Tomasino, B., and Rumati, R. I. (2013). At the mercy of strategies: The role of motor representations in language understanding. *Frontiers in Psychology*, 4(27).
- Tsakiris, M. (2010). My body in the brain: A neurocognitive model of body-ownership. *Neuropsychologia*, 48, 703–12.
- Tucker, M., and Ellis, R. (1998) On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 830–46.
- Wauters, L. N., Tellings, A. E. J. M., van Bon, W. H. J., and van Haaften, A. W. (2003). Mode of acquisition of word meanings: The viability of a theoretical construct. *Applied Psycholinguistics*, 24, 385–406.
- Whorf, B. L. (1956). *Language, thought, and reality; selected writings*, Cambridge, Technology Press of Massachusetts Institute of Technology.
- Wiemer-Hastings, K., Krug, J., and Xu, X. (2001). Imagery, context availability, contextual constraints and abstractness. In *Proceedings of 23rd Annual Meeting of the Cognitive Science Society* (pp. 1106–11). Hillsdale, NJ: Lawrence Erlbaum Associates.
- Wilson, A. D., and Golonka, S. (2013). Embodied cognition is not what you think it is. *Frontiers in Psychology*, 4(58).
- Winter, B., and Bergen, B. (2012). Language comprehenders represent object distance both visually and auditorily. *Language and Cognition*, 4, 1–16.
- Zwaan, R. A. (2004). The immersed experiencer: Toward an embodied theory of language comprehension. In B. H. Ross (Ed.), *The psychology of learning and motivation* (Vol. 43, pp. 35–62). New York: Academic Press.
- Zwaan, R. A., Madden, C. J., Yaxley, R. H., and Aveyard, M. E. (2004). Moving words: Dynamic representations in language comprehension. *Cognitive Science*, 28, 611–19.
- Zwaan, R. A., and Pecher, D. (2012). Revisiting mental simulation in language comprehension: Six replication attempts. *PLoS One*, 7, e51382.
- Zwaan, R. A., Stanfield, R. A., and Yaxley, R. H. (2002). Language comprehenders mentally represent the shapes of objects. *Psychological Science*, 13, 168–71.

14

LINKING WORDS TO WORLD

An embodiment perspective

Chen Yu

Introduction

Children begin to comprehend words at 9 months. They say their first word at around 12 months. The pace with which children add new words to receptive and productive vocabulary then accelerates such that by 24 to 30 months, children add words at the staggering rate of 5 to 9 new words a day (Bloom, 2000). Just as in many other cognitive learning tasks, a critical problem in word learning is the uncertainty and ambiguity in the learning environment – young word learners need to discover correct word-referent mappings among many possible candidate words and many possible candidate referents from potentially many objects that are simultaneously available. For example, Quine (1960) famously presented the core problem for learning word meanings from their co-occurrence with perceived events in the world. He imagined an anthropologist who observes a speaker saying “gavagai” while pointing in the general direction of a field. The intended referent (rabbit, grass, the field, or rabbit ears, etc.) is indeterminate from this example.

Past work has shown that the social context plays a key role in young learners’ prowess in disambiguating cluttered learning situations. The literature provides many powerful demonstrations of how social-interactional cues guide infants’ word learning, and in many cases, these seem essential to successful learning (Baldwin, 1993; Tomasello and Akhtar, 1995; Woodward and Guajardo, 2002; Bloom, 2000). Often the importance of social cues is interpreted in terms of children’s understanding that words are used with an “intent to refer.” Thus children’s early dependence on social cues is seen as a diagnostic marker of their ability to infer the intentions of the speaker. This kind of social cognition is called “mindreading” by Baron-Cohen (1997) or more generally “theory of mind” (Wellman and Liu, 2004). Consistent with these ideas, studies have shown that very young learners map nouns to objects only when the speaker is intentionally attending to the named object and not, for example, when there is an accidental co-occurrence of object and name (Tomasello, 2000). Such results point to the importance of understanding the social structure of learning experiences. However, there is much that is still not understood:

- (1) At the behavioral level, most studies have examined early word learning in constrained experimental tasks with only one or two objects in view. The adult partner (usually the

experimenter) is focused on the child, on effective teaching, and provides clear and repeated signals of her attention to the object being named. In this way, the attentional task is simple, and easily described in discrete and categorical terms (the attended object vs. the distractor). These contexts are not at all like the real world in which word learning is embedded in *a stream of activity* – in which parents both react to and attempt to control toddler behaviors and in which toddlers react to, direct, and sometimes ignore parents as they pursue their own goals. If we are going to understand the role of social cues in real-world word learning, we need to study social interactions and learning as they unfold in real time in dynamically complex and cluttered contexts.

- (2) At the theoretical level, the focus on macro-level behaviors and folk-psychological constructs does not connect easily to the real-time events in which learning happens. Current theoretical models explain the role of social cues in word learning via *internal* computations – mental models about the intentional states of the social partner and inferences about the goals and plans of the other (Breazeal and Scassellati, 2000). It is not at all clear that such abstract logic-like inferences about the internal states of others can happen *fast enough* to explain the exquisite real-time “dance” of social interactions in which effective adjustments within the dyad happen in fractions of seconds.
- (3) At the computational level, the analysis of the learning task has been based on an *adult’s* – and *third person’s* – view of the learning environment. Experimenters and theorists of children’s word learning are adults with a mature and developed view of the structure of the learning task and of the attentional and intentional states of the learner. As observers, we watch interactions between child and parent and we interpret these interactions from a vantage point that sees both the causes and effects of each action on each participant. It is seductively easy to describe such events in folk-psychological terms that sound like explanations: “the mother tried to elicit the child’s attention by waving the toy,” “the child wanted the toy and so reached for it.” There are many philosophical, methodological, and theoretical problems with this (Pfeifer and Scheier, 1999). One straightforward problem is that the third-person observer’s view (the experimenter’s view, etc.) of the learning task is not the learner’s view. Instead, what the learner sees – moment to moment – is a dynamic event that depends on the learner’s own momentary interests and *bodily orientation*. Recent studies using head-mounted cameras indicate that the adult view of the learning task *does not align at all with the dynamic first-person view of toddlers*, and is, therefore, a poor basis for theorizing about underlying processes (Pereira, Smith, and Yu, in press; Smith, Yu, and Pereira, 2011; Yu, Smith, Shen, Pereira, and Smith, 2009).

In brief, traditional theories of learning and intelligence (and many contemporary theories of development, learning, and social interaction) concentrate on internal representations and inferences from those representations, paying little attention to the body and to the ways intelligence is affected by and affects the physical world. More recently, there has been a shift toward ideas of embodiment, that intelligence emerges in the interaction of an agent *and its body* with an environment (Brooks and Stein, 1994; Clark, 2008; Ballard, Hayhoe, Pook, and Rao, 1997; Pfeifer and Scheier, 1999; Gibbs, 2006; Shapiro 2011; Spivey, 2007). In these analyses, the body – its morphology and its own intrinsic dynamics – plays just as important role as the internal cognitive system and physical environment. Beer (1995) provided a principled theoretical analysis of these ideas in which behavior and cognition are understood as arising from the dynamical interaction between a brain (or cognitive system), body, and environment which critically includes other brain-body-environment systems as shown in Figure 14.1 (left). From this perspective, the behavior and cognition *of an individual* may be conceptualized as arising from the

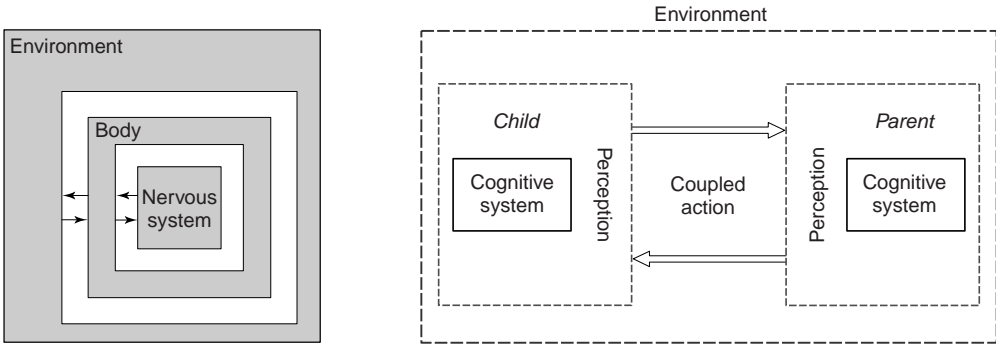


Figure 14.1 Overview of embodied social interaction. (Left) The brain-body-environment system in Beer (1995). (Right) Our proposed coupled embodied framework of child-parent interaction and communication.

closed-loop interaction of the cognitive system with the body and environment in which it is embedded, rather than as the sole product of any one component of this coupled system, such as the brain or internal representations. The behavior and collaboration of several individuals – for instance, word learning from child-parent social interaction – may be conceptualized as the *coupling* of these two systems as illustrated in Figure 14.1 (right).

Further, the critical role of embodiment has been demonstrated empirically and computationally in various behavioral science fields. For example, Ballard *et al.* (1997) proposed a model of “embodied cognition” that operates at timescales of approximately one-third of a second and uses subtle orienting movements of the body during a variety of cognitive tasks as input to a computational model. At this “embodiment” level, the constraints of the body determine the nature of cognitive operations, and the body’s pointing movements are used as deictic (pointing) references to bind objects in the physical environment to variables in cognitive programs of the brain. In our studies of child word learning, we emphasize the dependencies between the learner’s *own actions* and the learner’s internal cognitive state. Accordingly, understanding how the sensorimotor dependencies in the child affect cognition and learning – how, for example, looking at an object, or holding it – may engage and maintain attention is viewed as critical. These sensorimotor-cognition couplings also mean that the momentary sensorimotor actions of the learner are likely to be indicative of the learner’s internal state (Yu, Ballard, and Aslin, 2005). The basic idea behind our research is that the body – and its momentary actions – are crucial to social collaboration. Toward this goal, we seek to simultaneously measure multiple streams of behaviors and then to use data mining and machine learning techniques to *discover* patterns that support smooth interactions and word learning. We concentrate on measuring multiple streams of sensorimotor data because ultimately it is these coupled real-time behaviors that create the learning input and the learning environment.

A case study: multimodal word learning

Experiment

Here we describe a general experimental context that has been developed and used to understand word learning through parent-child interaction (Yu and Smith, 2012; Smith *et al.*, 2011). The experimental task is unconstrained tabletop play between a toddler (children between 15 and 20

months of age) and a parent. We chose the context of parent and child playing with toys on a tabletop as our naturalistic context for three reasons: (1) it is a common everyday context in which parents and toddlers are jointly engaged and in which word learning takes place (Callanan, 1985, 1990); (2) it is attentionally complex in that there can be many objects on the table, multiple and competing goals, and many shifts in attention; and (3) the geometry of tabletop play is sufficiently constrained that we can measure the first-person view and the head and hand movements of each participant. Figure 14.2 shows the basic set-up. The interaction is recorded

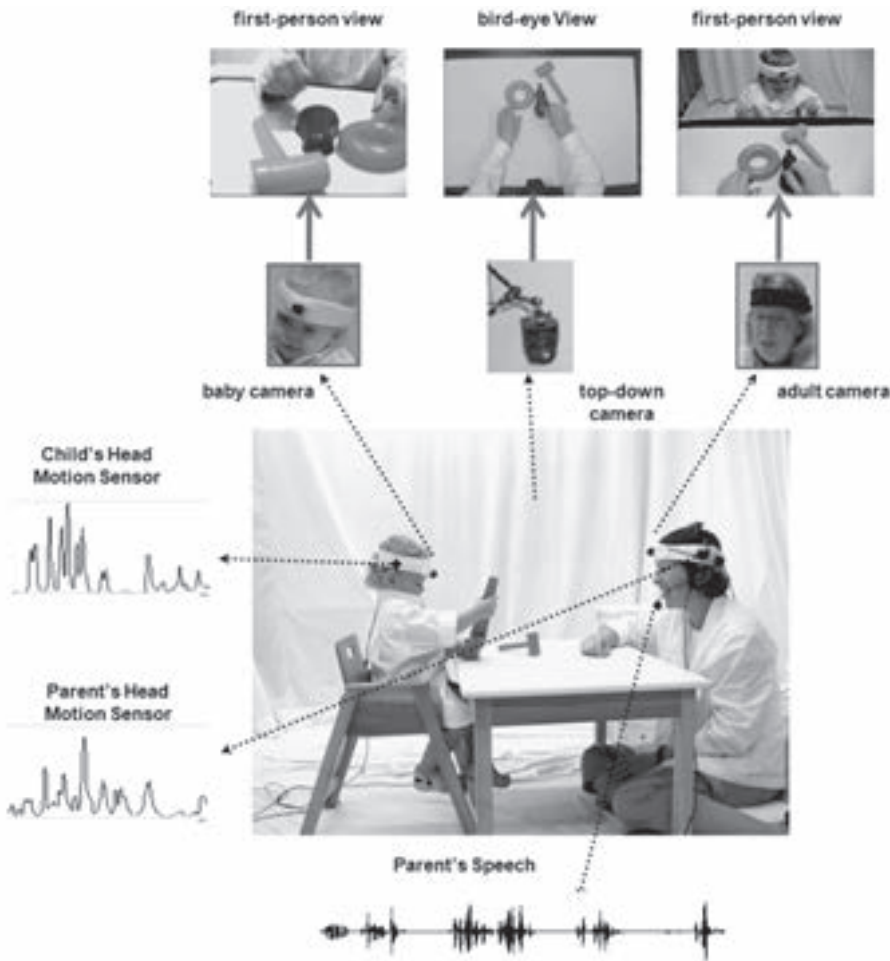


Figure 14.2 A multisensory system to collect multimodal data from child-parent interaction. The young word learner and the language teacher play with a set of objects at a table. Two mini cameras are placed onto the child's and the mother's heads respectively to collect visual information from two first-person views. Note that these two views are dramatically different. A third camera mounted high above the table records the bird's-eye view of the whole interaction. The participants also wore motion sensors to track their head and hand movements. A headset was used to record the caregiver's speech. In this way, we collected multimodal multistreaming data to analyze and detect interactive perception-action patterns from both the child and the parent that lead to successful word learning.

by three cameras: one head-mounted camera provides information about the scene from the child's point of view; a second head-mounted camera provides the parent's viewpoint; and a third from a top-down third-person viewpoint allows a clear observation of exactly what was on the table at any given moment (mostly the participants' hands and the objects being played with). We also measure both the child's and the parent's head and hand movements with a Polhemus 6 Degree-of-Freedom motion-tracking system and also the parent's speech through a headset. A particularly important and novel component of our method is the recording of visual information from the *learner's point of view* via a lightweight mini-camera mounted on a sports headband and placed low on the forehead. The angle of the camera is adjustable, and has a visual field of approximately 90 degrees, horizontally and vertically.

Parents were told that their goal was simply to engage the child with the toys and that they should interact as naturally as possible. The experimental objects were simple novel objects with novel names. Parents were taught the names prior to the experiment. Besides that, there were no constraints on what parents (or the children) had to say or what they had to do. Parents were told to engage their child with objects, to use the names we supplied *if* they named them, and that we were interested in the dynamics of parent-child play with toys. There were three toy objects in each of the three trials. At the end of interaction, we also tested each child's knowledge of the names of the nine objects that they played with, using a standard forced choice procedure. In this way, we used – as described above – completely novel methods of collecting multiple streams of sensorimotor data during the course of the learning experiences but we tied these measures to well-documented, standard, and highly reliable measures of word learning.

Video, motion-tracking, and speech data were coded to extract sensorimotor variables, such as object size in view, holding activities from both participants, and head stability. Technical details can be found in Yu and Smith (2012); Yu *et al.* (2009). As a result, we have collected and extracted multiple time series that capture visual, motor, and speech behaviors moment by moment from both the child and the parent. Those derived data were further analyzed to discover various sensory and motor patterns from child-parent interactions.

Results

During the play session, parents uttered on average 365 words (tokens). Each of the 9 object names was produced by the parents on average only 5.32 times (standard deviation [SD] = 1.12). An object name was categorized as learned for an infant if his looking behavior at test indicated learning. The number of times parents named each object was negatively correlated with the likelihood that the infant learned the object name: 4.5 naming events for learned names and 6.5 per name for unlearned names. This may be due to parents' use of the name in attempts to engage children with specific objects that were not of interest to the child. At any rate, the lack of correlation reminds us that learning may depend on more than the mere frequency of heard names and more critically on the frequency with which naming coincides with the infant's visual selection of the named object. All parent naming events associated with learned object names were designated as "successful" ($n = 149$). All other object-naming events were designated as "unsuccessful" ($n = 136$). Recall that objects were presented in three sets of three. Successful and unsuccessful naming events did not differ in duration, nor in any other noticeable property.

Our first hypothesis was that toddlers may solve the referential uncertainty problem at a sensory level. To test this hypothesis, we measured the size of the named target and the size of other *distractor* objects in the head-camera images. This provided a measure of the relative dominance of the referent of the object name and its visual competitors. The sizes of the target

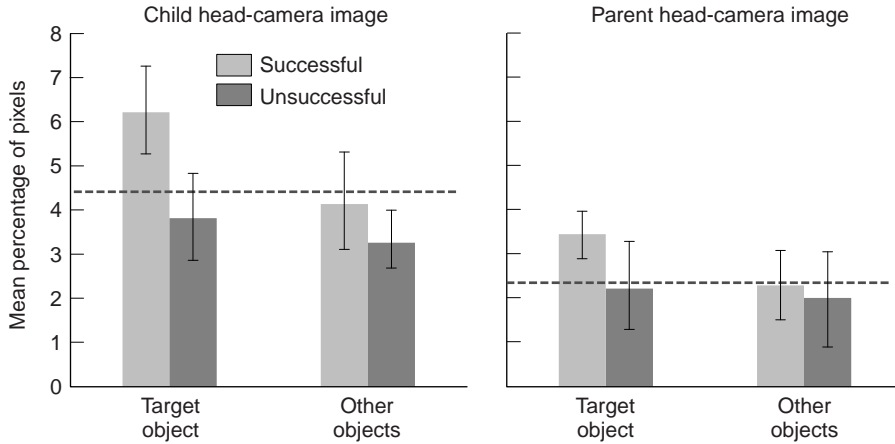


Figure 14.3 Mean object size (% pixels in image) for the named target, and for other objects in child's and parent's head-camera images during the naming event, for successful naming events that led to learning at post-test and for unsuccessful naming events that did not lead to learning as measured by test. Means and standard errors calculated with respect to trials. Dashed line indicates the mean object size during non-naming moments.

and other objects in both the infant and the parent head-camera views during naming events are shown in Figure 14.3. Consider first the pattern from the child's head-camera images. The image sizes of the named target in the child head camera during *successful* naming events differed from non-naming events (mean object size, $M_{\text{Successful}} = 6.28\%$ of pixels in the image; object size is measured as the total number of object pixels divided by the head-camera image size) but the target object sizes for unsuccessful naming events did not ($M_{\text{Unsuccessful}} = 4.07\%$). This provides direct support for the hypothesis that referential selection at *input*, at the sensory level, matters to successful object name learning by infants. However, parent naming versus not naming was not strongly associated with the visual dominance of the target object in the child's view. Parents produced nearly as many unsuccessful naming events as successful ones, and only successful naming events show the visual signature of target objects in the child's view. Notice also that the named target object was larger in the child's head-camera view for successful than for unsuccessful naming events ($M_{\text{Successful}} = 6.28\%$; $M_{\text{Unsuccessful}} = 3.88\%$). We also examined whether these differences changed over the course of the play session: it could be that infants learned some words early in the session and because they knew these words, they might interact with the objects differently or parents might name objects differently early versus later in play. Comparisons of the relative dominance of the named object for the first three versus second three play trials did not differ for either successful or unsuccessful naming events. These analyses provide strong support for the relevance of visual information at the moment an object name was heard for the learning of that name by 18-month-old infants.

Now consider these same measures for the parent head-camera images, also shown in Figure 14.3. The image size of the objects was always smaller (because the objects tend to be farther away) in the parent's than in the infant's head-camera images. However, the pattern of image size for the named object for successful versus unsuccessful naming events *is the same for parents and infants*. More specifically, for the parent head-camera images, the named target was larger in the parents' head-camera image during successful than unsuccessful naming moments ($M_{\text{Successful}} = 3.46\%$; $M_{\text{Unsuccessful}} = 2.29\%$) and differed reliably from the comparison measure for non-naming

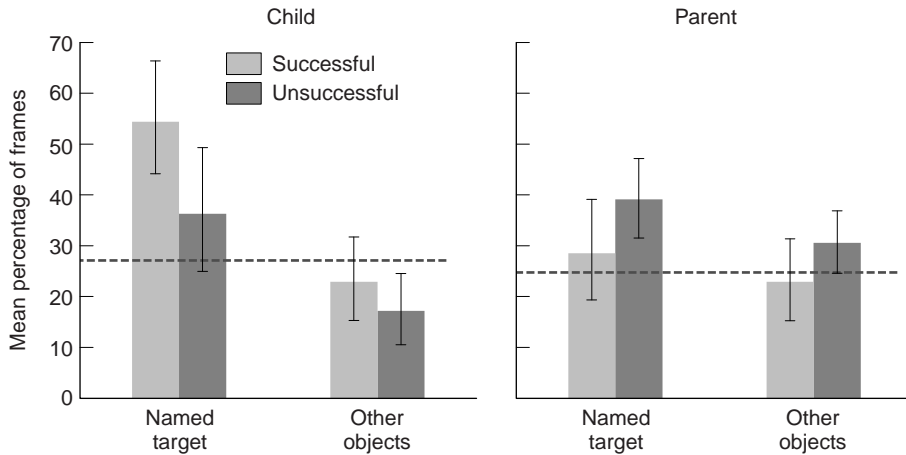


Figure 14.4 Mean percentage of frames in which the parent or child was holding the named object or another object for successful and unsuccessful naming events. Means and standard errors calculated with respect to trials. Dashed line indicates mean holding for children and parents during non-naming moments.

events ($M_{\text{Non-naming}} = 2.36\%$). Considering that the target object was closer to the child (as established in the analyses of the child head-camera images), this pattern can happen *only* if parents move their head toward the named target (and child) during the naming event, thereby reducing the distance between the object and the head (and the head camera). In brief, the target object was more visually dominant in *both* the infant's and the parent's view during successful but not unsuccessful naming events, indicating coordinated and joint attention during successful naming events.

Visual selection and the reduction of referential ambiguity at the sensory level, at input, must be accomplished by changing the physical relation between the potential visual targets and the eyes. Hand actions that move the object close to the head and eyes and the quieting of head movements that stabilize the view are thus potentially important components of visual selection. The left side of Figure 14.4 shows that infants were more likely to be holding the named object than other objects during both successful and unsuccessful naming events but holding was more strongly associated with successful than unsuccessful naming events. The object-holding behavior of parents, shown on the right side of Figure 14.4, was not reliably related to naming or to the learning of the object name. But notice there was a slight tendency for parents to be holding the named object during *unsuccessful* naming events; in the present task, parents did not often jointly hold the object that the child was holding and thus parent-holding is associated with not-holding by the child, which, in turn is associated with less visual dominance for the named target and with a decreased likelihood of learning the object name.

If sustained visual selection is critical to infant learning, then learning may also depend on the quieting of head movements to stabilize the selected object in the visual field. Figure 14.5 shows the percentage of time that infants and adults were moving their head during successful, non-successful, and non-naming events. For both head orientation and position and for both parents and infants, successful naming events are characterized by *less* head movement, suggesting the importance of stabilized visual attention. The fact that both parents and infants stabilized attention on the named object during successful but not unsuccessful naming events again points to coordinated or joint attention at the sensorimotor level. Considering the evidence on

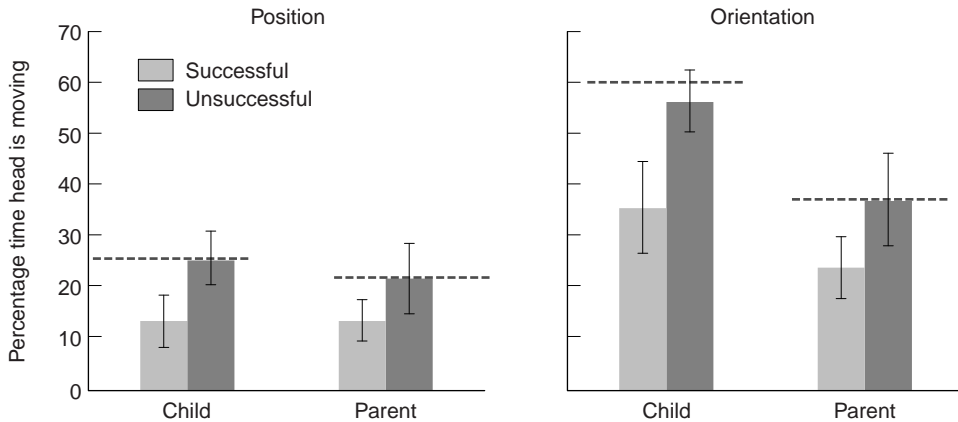


Figure 14.5 Mean percentage time with position and orientation head movements during successful and unsuccessful naming events for children and parents. Means and standard errors calculated with respect to trials. Dashed line indicates mean movements during non-naming moments.

hands and heads together, successful naming events in the present context appear to have the following properties. During successful naming events, infants tend to hold the target object and visually isolate that object for some time before and after it is named, and in doing so, they stabilize head movements, maintaining this visual dominance of the selected object. During successful naming events, parents tend, immediately prior to the naming event, to move their heads toward the named object and to hold the head steady at that moment, directed at the named object, but this increased visual dominance of the named object for the parent does not last and is localized to the naming event itself. Unsuccessful naming events have a different character, one in which both manual and visual attention on the part of the infant is more transient and one in which the visual field is more cluttered with other objects as large in the view as the named object. Both child's and parent's head movements may also reflect this greater clutter and more transient attention during non-successful naming events as infants and parents are less likely to move their heads toward the target object and less likely to stabilize the head.

General discussion

The problem of referential uncertainty, a fundamental one for learners who must learn words from their co-occurrence with scenes, is reduced if object names are provided when there is but one dominating object in the learner's view. The present results show that infants often create these moments through their own actions and that object naming during these visually optimal moments is associated with learning.

When infants bring objects close to their eyes and head, they effectively reduce the clutter and distraction in the visual field as close objects are visually large and block the view of potential distractors. This is a form of externally rather internally accomplished visual selection and it highlights how the early control of attention may be tightly linked to sensorimotor behavior. This is a particularly interesting developmental idea because many cognitive developmental disorders involve attention and because there is considerable evidence of comorbidity of these cognitive disorders with early usual sensorimotor patterns (Hartman, Houwen, Scherder, and Visscher, 2010).

Experimental studies of adults show that the mature system can select and sustain attention on a visual target solely through internal means, without moving any part of the body and while eye gaze is fixated elsewhere (e.g. Müller, Philastides, and Newsome, 2005; Shepherd, Findlay, and Hockey, 1986). However, visual attention is also usually linked to eye movements to the attended object's location (Hayhoe and Ballard, 2005). Moreover, eye movements (Grosbras, Laird, and Paus, 2005), head movements (Colby and Goldberg, 1992), and hand movements (Hagler, Riecke, and Sereno, 2007) have been shown to bias visual attention – detection and depth of processing – in the direction of the movement. This link between the localization of action and the localization of visual attention may be revealing of the common mechanisms behind action and attention as indicated by growing neural evidence that motor-planning regions play a role in cortical attentional networks (Hagler, *et al.*, 2007). Perhaps for physically active toddlers, visual attention is more tightly tied to external action and with development these external mechanisms become more internalized.

The present study also raises a discussion on the level of understanding. Children learn the names of objects in which they are interested. Therefore, as shown in Figure 14.6(a), “interest,” as a macro-level concept, may be viewed as a driving force behind learning (Bloom, Tinker, and Scholnick, 2001). Given this, what is the new contribution of the present study based on sensorimotor dynamics? One might argue that the main result is that infants learn object names when they are *interested* in those objects: that holding an object and a one-object view are merely indicators of the infant's interest in the object. That is, the cause of learning may not be the lack of visual clutter at the moment of object naming, but be the child's interest in the object which happens to be correlated with the not causally relevant one-object view. By this argument (as shown Figure 14.6(b)), the results show only that infants learn the names of things in which they are interested more readily than the names of things for which they have little interest; visual selection at the sensory level is merely an associated attribute but not essential, nor contributory, to learning. From this perspective, the present study has gone to a lot of trouble and a lot of technology to demonstrate the obvious. Although we disagree with this view, the proposal that our measures of image size and holding are measures of infants' interest in the target object and that the results show that infants learn when they are interested in an object seems absolutely right to us. What the present results add to the macro-level construct of “interest” are two alternative explanations shown in Figure 14.6(c) and (d). First, the present study may provide a mechanistic explanation at a more micro level of analysis of why “interest” matters to learning. As proposed in Figure 14.6(c), interest in an object by a toddler may often *create* a bottom-up sensory input that is clean, optimized on a single object, and sustained. Interest may mechanistically yield better learning (at least in part) *because* of these sensory consequences. Therefore, at the macro level, one may observe the correlation between learning and interest; at the micro level, the effect of interest on learning may be implemented through clean sensory input, and through perceptual and action processes that directly connect to learning. Figure 14.6(d) provides a more integrated version of these ideas: interest may initially drive both learning (through a separate path); and interest may also drive the child's perception and action – which feed back onto interest and sustained attention and support learning. That is, interest may drive actions and the visual isolation of the object and thus increase interest. These sensorimotor behaviors may also directly influence learning by localizing and stabilizing attention and by limiting clutter and distraction. In brief, the micro-level embodied analyses presented here are not in competition with macro-level accounts but offer new and testable hypotheses at a finer grain of mechanism – moving forward from Figure 14.6(a) to Figure 14.6(b), (c), and (d).

In conclusion, the main contribution of this research direction, then, is that it suggests a bottom-up embodied solution to word-referent learning by toddlers. Toddlers, through their

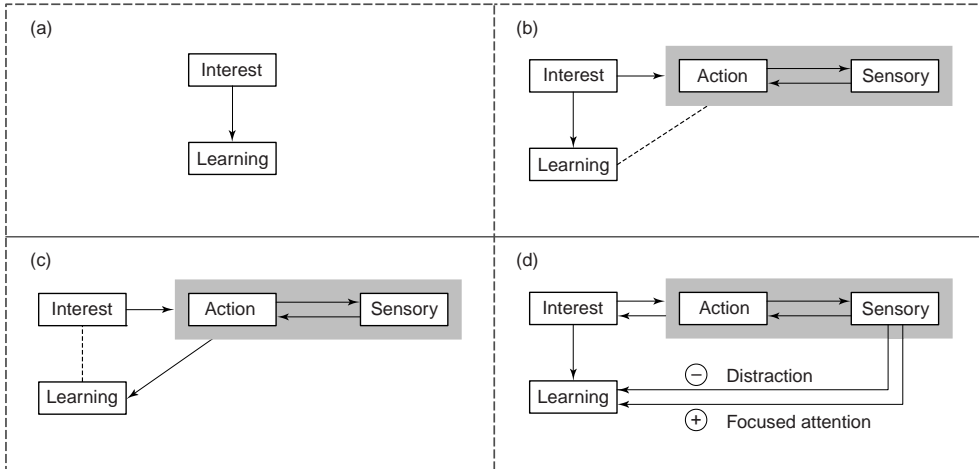


Figure 14.6 Four hypotheses on child's interest, learning and sensorimotor behaviors. (a) child's interest on target objects leads to learning. (b) Child's interest drives both learning and sensorimotor behaviors. Therefore, there are correlations between the two (the dashed line). (c) Child's interest leads to a sequence of actions on the interested object (e.g. holding and manipulating) which then lead to the visual dominance of that object. This clean visual input is fed into internal learning processes. In this way, child's interest is indirectly correlated to learning (the dashed line) because interest is implemented through child's perception and action which directly connect to learning. (d) Initially, child's interest directly influences both learning and sensorimotor behaviors. Thereafter, sensorimotor behaviors also directly influence learning (and maybe interest itself as well) as sustained attention to the target object may facilitate learning while distracting and messy sensory input may disrupt learning. In this way, both child's interest and sensorimotor behaviors jointly influence learning.

own actions, often create a personal view that consists of one dominating object. Parents often (but not always) name objects during these optimal sensory moments and when they do, toddlers learn the object name.

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References

- Baldwin, D. (1993). Early referential understanding: Infants' ability to recognize referential acts for what they are. *Developmental Psychology*, 29, 832–43.
- Ballard, D. H., Hayhoe, M. M., Pook, P. K., and Rao, R. P. N. (1997). Deictic codes for the embodiment of cognition. *Behavioral and Brain Sciences*, 20, 723–42.
- Baron-Cohen, S. (1997). *Mindblindness: An essay on autism and theory of mind*. Cambridge, MA: MIT Press.
- Beer, R. D. (1995). A dynamical systems perspective on agent-environment interaction. *Artificial Intelligence*, 72, 173–215.

- Bloom, L., Tinker, E., and Scholnick, E. K. (2001). *The intentionality model and language acquisition: Engagement, effort, and the essential tension in development*. Malden, MA: Wiley-Blackwell.
- Bloom, P. (2000). *How children learn the meaning of words*. Cambridge, MA: MIT Press.
- Breazeal, C., and Scassellati, B. (2000). Infant-like social interactions between a robot and a human caregiver. *Adaptive Behavior*, 8, 49.
- Brooks, R. A., and Stein, L. A. (1994). Building brains for bodies. *Autonomous Robots*, 1, 7–25.
- Callanan, M. A. (1985). How parents label objects for young children: The role of input in the acquisition of category hierarchies. *Child Development*, 508–23.
- (1990). Parents' descriptions of objects: Potential data for children's inferences about category principles. *Cognitive Development*, 5(1), 101–22.
- Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. Oxford: Oxford University Press.
- Colby, C., and Goldberg, M. (1992). The updating of the representation of visual space in parietal cortex by intended eye movements. *Science*, 255, 90.
- Gibbs, R. W. (2006). *Embodiment and cognitive science*. Cambridge: Cambridge University Press.
- Grosbras, M. H., Laird, A. R., and Paus, T. (2005). Cortical regions involved in eye movements, shifts of attention, and gaze perception. *Human Brain Mapping*, 25, 140–54.
- Hagler, D., Jr., Riecke, L., and Sereno, M. (2007). Parietal and superior frontal visuospatial maps activated by pointing and saccades. *Neuroimage*, 35, 1562–77.
- Hartman, E., Houwen, S., Scherder, E., and Visscher, C. (2010). On the relationship between motor performance and executive functioning in children with intellectual disabilities. *Journal of Intellectual Disability Research*, 54, 468–77.
- Hayhoe, M., and Ballard, D. (2005). Eye movements in natural behavior. *Trends in Cognitive Sciences*, 9(4), 188–94.
- Müller, J. R., Philastides, M. G., and Newsome, W. T. (2005). Microstimulation of the superior colliculus focuses attention without moving the eyes. *Proceedings of the National Academy of Sciences of the United States of America*, 102(3), 524–29.
- Pereira, A. F., Smith, L. B., and Yu, C. (in press). A bottom-up view of toddler word learning. *Psychological Bulletin and Review*.
- Pfeifer, R., and Scheier, C. (1999). *Understanding intelligence*. Cambridge, MA: MIT Press.
- Quine, W. (1960). *Word and object*. Cambridge, MA: MIT Press.
- Shapiro, L. (2011). *Embodied cognition*. London: Taylor & Francis.
- Shepherd, M., Findlay, J., and Hockey, R. (1986). The relationship between eye movements and spatial attention. *Quarterly Journal of Experimental Psychology Section A*, 38(3), 475–91.
- Smith, L. B., Yu, C., and Pereira, A. F. (2011). Not your mother's view: The dynamics of toddler visual experience. *Developmental Science*, 14, 9–17.
- Spivey, M. (2007). *The Continuity of Mind*. New York: Oxford University Press.
- Tomasello, M. (2000). The social-pragmatic theory of word learning. *Pragmatics*, 10, 401–13.
- Tomasello, M., and Akhtar, N. (1995). Two-year-olds use pragmatic cues to differentiate reference to objects and actions. *Cognitive Development*, 10, 201–24.
- Wellman, H. M., and Liu, D. (2004). Scaling of theory-of-mind tasks. *Child Development*, 75, 523–41.
- Woodward, A. L., and Guajardo, J. J. (2002). Infants' understanding of the point gesture as an object-directed action. *Cognitive Development*, 17, 1061–84.
- Yu, C., Ballard, D. H., and Aslin, R. N. (2005). The role of embodied intention in early lexical acquisition. *Cognitive Science: A Multidisciplinary Journal*, 29, 961–1005.
- Yu, C., and Smith, L. B. (2012). Embodied attention and word learning by toddlers. *Cognition*, 125, 244–62.
- Yu, C., Smith, L. B., Shen, H., Pereira, A., and Smith, T. (2009). Active information selection: Visual attention through the hands. *IEEE Transactions on Autonomous Mental Development*, 2, 141–51.

GESTURE IN REASONING

An embodied perspective

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Introduction

Theories of embodied cognition claim that cognitive processes are rooted in interactions of the human body with the physical world. The core idea is that cognition depends on the specifics of the body and its actual or possible actions in the world. This embodied perspective is the basis for a diverse set of theoretical positions and specific claims regarding perception, cognition, and language (Anderson, 2003; Shapiro, 2011; Wilson, 2002). In this chapter, we take an embodied perspective on *reasoning*, which we define as cognitive processing in service of inference, judgment, or solving problems. We review research relevant to two central claims of the embodied cognition perspective: (1) reasoning is based in perception and action; and (2) reasoning is grounded in the physical environment.

A growing body of research shows that actions – including both physical actions that people perform and simulated actions that people imagine – can affect reasoning and problem solving. In this chapter, we focus on one special type of action – gesture. Gestures are movements of the hands and body that are integrally connected with thinking, and often, with speaking.

Many past studies have considered speakers’ gestures as evidence that the knowledge expressed in those gestures is “embodied.” Indeed, a recent theoretical account, the Gesture as Simulated Action (GSA) framework (Hostetter and Alibali, 2008), holds that gestures derive from simulated actions. This view builds on the idea that mental simulations of actions and perceptual states activate the same neural areas that are used in actual actions and perception. According to the GSA framework, this activation is not always completely inhibited during speaking, and it can be expressed in gestures.

From this perspective, then, gestures yield evidence for the embodiment of cognition because they derive from simulated actions and perceptions. At the same time, gestures are also actions. As such, gestures may directly affect thought, in many of the same ways that action can.

In this chapter, we focus on gesture and its role in an embodied account of reasoning. We first address the distinction between action and gesture. We then consider three broad claims regarding gesture and reasoning: (1) gesture production manifests embodied processes in reasoning; (2) gesture production plays a causal role in reasoning by raising activation on perceptual-motor information; and (3) gesture communicates information that affects listeners’ reasoning.

What are gestures?

Actions are movements of parts of the body. As such, actions involve an interaction between an individual and the physical environment. In many cases, actions involve manipulating or moving objects. *Gestures* are a special form of action that typically do not involve acting on the environment or manipulating objects. Instead, gestures involve moving a part of the body (often the hands or arms) in order to express an idea or meaning. Gestures are not produced in order to act upon the world; instead, they are produced as part of the cognitive processes that underlie thinking and speaking.

The distinction between gestures and other actions is not always clear-cut. Gestures typically represent things without utilizing objects; however, in some cases people use objects to gesture (e.g. pointers). Additionally, people may hold up or manipulate objects in the course of speaking or thinking in ways that seem to be gestures. Some researchers consider only movements produced along with speech to be gestures (e.g. Goldin-Meadow, 2003, p. 8), while others take a broader view, including movements produced when thinking in silence (e.g. Chu and Kita, 2011). Our focus in this chapter is on gestures as a form of action, so we take a broad perspective. We consider gestures to be actions that are produced as part of the cognitive processes involved in speaking or thinking.

Several classification systems for gestures have been proposed (e.g. McNeill, 1992). Our focus in this chapter is primarily on *representational* gestures, which are gestures that depict some aspect of their meaning via hand shape or motion (e.g. moving the hand in a circle to represent *spin*). We also consider *pointing* gestures, a subtype of representational gestures, which indicate objects or locations. These types of gestures can be distinguished from *beat* gestures, which are motorically simple, rhythmic movements, akin to beating time, and *interactive* gestures, which are used to regulate turn-taking and other aspects of interaction.

There are a number of contemporary theories about the cognitive processes that give rise to gestures (e.g. Kita and Özyürek, 2003; McNeill, 2005). One perspective, the GSA framework (Hostetter and Alibali, 2008), builds on an embodied perspective on language and cognitive processing, and makes explicit ties to action. Simply stated, the GSA framework proposes that gestures derive from simulated actions or perceptual states, which people utilize when thinking or when producing or comprehending language. These simulated actions and perceptual states activate corresponding motor and premotor areas of the brain (e.g. Hauk, Johnsrude, and Pulvermüller, 2004). When activation in these areas exceeds a critical threshold, people may produce overt movements, which we recognize as representational gestures.

The GSA framework builds on research establishing the role of action simulations in language comprehension (see Fischer and Zwaan, 2008, for review). For example, Glenberg and Kaschak (2002) studied comprehension of sentences that implied movement either towards or away from the body. Comprehension was affected by the direction of action required to make a response – compatible actions facilitated comprehension, and incompatible actions inhibited comprehension. Importantly, these findings held true both for sentences about literal movements (e.g. close the drawer) and sentences that implied movement figuratively (e.g. tell a story). These findings suggest that simulations of action are involved in language *comprehension*. The GSA framework holds that such simulations are also involved in language *production*, and that these simulations give rise to gestures.

Hostetter and Alibali (2010) tested the claim that gestures arise from highly activated simulations of action. In a series of experiments, they found that participants produced more gestures when describing information they acquired through physical actions compared with information they acquired visually. This evidence supports the central claim of the GSA framework, namely that gestures arise when speakers strongly simulate actions.

According to the GSA framework, gestures are particularly likely to occur along with speech, because the combined activation from speech production and mental simulation is likely to exceed the speaker's gesture threshold. However, producing speech is not necessary for a gesture to occur. In some cases, activation on action simulations can exceed the gesture threshold, even without the extra "boost" in activation provided by speech production. For example, when performing mental rotation tasks, many participants spontaneously produce gestures, even when they do not speak aloud (Chu and Kita, 2011). Similarly, when given a configuration of gears and asked to predict the movement of a specific gear without talking aloud, many participants spontaneously produce gestures depicting gear movements (Alibali, Spencer, Knox, and Kita, 2011, experiment 2). These studies suggest that people gesture when they engage in cognitive processing that involves highly activated simulations of actions or perceptual states, even if they are not also producing speech.

Gesture production manifests embodied processes in reasoning

The embodied cognition perspective holds that thought is based in perception and action. If gestures do, in fact, derive from simulated actions and perceptual states, as claimed by the GSA framework, then gestures provide *prima facie* evidence for this claim. When speakers express ideas that they mentally represent in simulations of actions and perceptual states, they naturally produce gestures, and these gestures manifest the embodied nature of those ideas.

Gestures that manifest simulated actions and perceptions commonly occur with the verbalizations that people produce during reasoning and problem-solving tasks. Not surprisingly, people often produce gestures when talking about *bodily actions* that they have performed (or could perform). For example, Cook and Tanenhaus (2009) studied the gestures participants produced when explaining their solutions to the Tower of Hanoi puzzle, which they had solved either using real disks and pegs or on a computer. Participants in both conditions described moving the disks in speech and gestures, but participants in the real-objects condition produced a greater proportion of gestures that used grasping hand shapes (like the actions they produced when actually moving the disks) than participants in the computer condition. Thus, people's gestures were aligned with the actual actions they had produced earlier in the experiment, which they presumably called to mind when explaining their solutions.

People also produce gestures when they engage in other forms of reasoning that involve simulated actions and perceptions, such as when they reason about physical forces (Roth, 2002) or when they form or manipulate mental images of objects or scenes that are not physically present (Chu and Kita, 2008; McNeill *et al.*, 2001). For example, Singer, Radinsky, and Goldman (2008) described the gestures children in a science class produced when discussing data about earthquakes and volcanoes. The children frequently produced representational gestures depicting the movements of tectonic plates, including rift, subduction, and buckling.

Perhaps most surprising is that people also use representational gestures when reasoning about *abstract ideas*. Several accounts of human cognition are compatible with the idea that simulations of actions and perceptual states are activated when thinking about abstract concepts (e.g. Barsalou, Simmons, Barbey, and Wilson, 2003; Glenberg *et al.*, 2008; Lakoff and Johnson, 1980). Lakoff and Johnson (1980) argued that many abstract concepts are understood in terms of metaphors that are based in the body or in human experience. These metaphors are sometimes manifested in the gestures that people produce when speaking or reasoning about abstract concepts. For example, one conceptual metaphor that applies in early mathematics is ARITHMETIC IS COLLECTING OBJECTS (Lakoff and Núñez, 2001), and this metaphor has been observed in gestures.

Marghetis, Bergen, and Núñez (2012) describe a student who says, “Because you add the same numbers” while producing a gesture in which she brings her hands, in grasping hand shapes, together in front of her body, representing gathering two collections or masses. Thus, evidence from gestures suggests that adding abstract entities, such as numbers, may involve a mental simulation of the physical action of collecting objects. Even abstract notions, such as mathematical concepts, are rooted in bodily actions.

Thus far, we have focused on gestures that display elements of people’s mental simulations of actions and perceptual states by virtue of their form (hand shape or motion trajectory). However, not all gestures depict semantic content in this way; instead, some gestures express information by *pointing*. Pointing gestures index objects and locations in the physical world, and they have meaning by virtue of this indexing function (Glenberg and Robertson, 2000). A pointing gesture may directly refer to the object or location that it indicates (e.g. pointing to a cup to refer to that cup), or it can refer indirectly to a related or perceptually similar object (e.g. pointing to a cup on one’s desk to refer to a cup at home) (Butcher, Mylander, and Goldin-Meadow, 1991). Pointing gestures can even refer metaphorically to abstract ideas by indicating “places” for those ideas (e.g. gesturing to one side to indicate the “pros” of a decision, and to the other side to indicate the “cons”). Thus, pointing gestures manifest another of the core claims of many theories of embodied cognition, namely, the notion that cognition is tied to the environment. Pointing gestures suggest that speakers utilize the environment as “part” of their cognitive system, by indexing present objects and locations, as well as non-present objects and locations, and even non-tangible ideas.

Thus, there are multiple ways in which gesture manifests embodied processes in human reasoning (see Alibali and Nathan, 2012, for further discussion). First, representational gestures display elements of mental simulations of actions and perceptual states. Second, some representational gestures reveal body-based and experiential metaphors that are associated with, and may underpin, certain abstract concepts. Finally, pointing gestures index words and ideas to the physical world. Thus, gestures suggest that cognition is both rooted in perception and action, and grounded in the physical environment.

Gesture production plays a causal role in reasoning

We have argued that gestures *reflect* thoughts that are grounded in sensory and motor processes – thus, gestures manifest embodied thinking. However, gestures may also do more. In this section, we present evidence that producing gestures can *affect* thought by increasing activation on perceptual and motor information.

Several studies have shown that *actions* can facilitate problem solving when they embody a problem’s solution (e.g. Catrambone, Craig, and Nersessian, 2006). For example, Thomas and Lleras (2007) asked participants to solve Duncker’s (1945) radiation problem, in which a doctor tries to destroy a tumor with a ray. If the ray is directed at the tumor with enough intensity to destroy it, it will also destroy the healthy tissue it passes through. At lesser intensities, the ray can safely pass through healthy tissue, but will not affect the tumor. The solution is to split the ray into multiple, less intense rays that will converge on the tumor. Participants worked on the radiation problem and took frequent breaks to do a seemingly unrelated eye-tracking task, in which they directed their eyes to a digit among an array of letters. In the critical condition, the location of the digits required that participants move their eyes repeatedly from the periphery of the screen to the center, mirroring the rays converging on the center from different locations. Participants who produced these seemingly unrelated eye movements were more likely to solve the radiation problem than participants who produced other eye movement patterns.

The effect of action is not limited to eye movements. Thomas and Lleras (2009) asked participants to solve Maier's (1931) two-string problem, which requires figuring out how to tie together two strings that are hanging from the ceiling at a far enough distance that participants cannot reach one while holding the other. The solution is to tie a pair of pliers that is available in the room to one string so that it will swing like a pendulum. Participants who took problem-solving breaks in which they engaged in arm-swinging "exercises" were more likely to solve the problem than were participants who engaged in stretching exercises that did not embody the problem's solution. Moreover, this effect held even for participants who were not aware that there was a connection between their movements and the solution.

These studies suggest that *actions* affect problem solving, but what about gestures? As discussed above, gestures are a special kind of action produced as part of the cognitive processes involved in speaking or thinking. In contrast to the arm-swinging movements produced by participants in Thomas and Lleras's (2009) study, gestures manifest specific ideas that people have in mind. According to the GSA framework, speakers produce gestures because they mentally simulate actions or perceptual states, and gestures represent salient or highly activated elements of those simulations.

Recent work suggests that, not only do gestures manifest elements of peoples' mental simulations, they can also affect those simulations, and thereby influence memory and problem solving (Cook, Yip, and Goldin-Meadow, 2010; Wesp, Hess, Keutmann, and Wheaton, 2001). The available data suggest that producing gestures raises activation on perceptual and motor elements of people's mental simulations, and highlights these elements as relevant and important for further cognitive processing (see Alibali and Kita, 2010; Goldin-Meadow and Beilock, 2010, for discussion).

In support of this view, when people gesture about a task or scene, they are especially likely to focus on perceptual elements of that task or scene. For example, Alibali and Kita (2010) asked children to explain their solutions to Piagetian conservation problems, with gesture either allowed or prohibited. Children were more likely to describe perceptually present information (e.g. perceptual features of the task objects, such as height, width, or length) when they gestured. When they did not gesture, children were more likely to describe how the problem looked previously or how it might look in the future, rather than how it looked at that moment. Thus, gestures appear to ground speakers' thinking and speaking in the perceptually present environment.

People can also use gestures to *generate* relational or action-based information that is not present in the problem at hand. Boncodd, Dixon, and Kelly (2010) asked preschool children to solve gear-system problems, in which they had to determine which direction a final gear would turn, given information about how an initial gear turned. Children often traced the alternating sequence of gears in gestures as they attempted to solve the problems. Moreover, the more children traced the sequence, the more likely they were to discover the new idea that adjacent gears turn in alternating directions. Note that the alternating movements were not actually present in the display – instead, children generated the notion of alternation in their gestures. Thus, gestures introduced new information into children's reasoning.

Gestures can also affect reasoning, even when problems involve no visual display at all. In one study, college students were asked to imagine lines of varying numbers of gears, and to predict the direction of movement of the final gear, given the movement of the initial gear. Participants talked out loud as they solved the problems, and for some participants, gesture was prohibited. Participants who were allowed to gesture were *less likely* to discover that odd-numbered gears turn in the same direction as the initial gear and even-numbered gears turn in the opposite direction (the *parity* rule) than were participants who were prevented from

gesturing. Instead, participants who were allowed to gesture tended to simulate the actions of each gear in order to predict the movement of the final gear (Alibali *et al.*, 2011, experiment 1). Thus, in this task, gestures highlighted perceptual and motor aspects of the task, even though those aspects were not perceptually present in the environment. Further, for this task, focusing on perceptual and motor information actually hindered performance, as it prevented participants from generating the highly efficient parity rule. Whether gesture helps or hinders seems to depend on whether perceptual and motor information is integral to the problem's solution.

This point is echoed in a recent study involving variations of the Tower of Hanoi puzzle (Beilock and Goldin-Meadow, 2010). When participants gestured about a version of the problem that had certain affordances (i.e. the smallest disk was the lightest), it impaired their ability to solve a version of the problem with different affordances (i.e. the smallest disk was the heaviest). Importantly, it was not simply talking about the problem or interacting with the initial version of the problem that impaired problem solving; on the contrary, only when speakers described their solution, and gestured while doing so, did they have difficulty solving the problem when the affordances changed. These findings suggest that gesturing about a particular simulation makes certain details of that simulation particularly salient in the speaker's mind. When the perceptual and motor details of that simulation are irrelevant to the problem, highlighting those details in gesture can be detrimental to problem solving.

In sum, there is considerable evidence to suggest that producing gestures highlights perceptual and motor information, both in the environment and in people's mental representations of tasks or scenes. As a result, when people produce gestures, they are more likely to incorporate perceptual and motor information into their reasoning.

Gesture communicates information that affects listeners' reasoning

Thus far, we have focused on gestures from the perspective of the individual who produces them. We have considered what gestures reveal about the cognitive processes of the gesturer, and we have considered the role of gesture in shaping those cognitive processes. In this section, we consider the other side of the interactional "coin" – that is, we consider speakers' gestures from the perspective of the listener (or observer). We argue that gesture may affect *listeners'* cognitive processing in two main ways. First, speakers' gestures may help listeners to *grasp speakers' referential intentions*, by indexing their utterances to objects or locations in the physical and socially shared environment. Second, speakers' gestures can help listeners to *grasp speakers' semantic intentions*, by helping them to simulate the actions and perceptual states that speakers have in mind.

As discussed above, pointing gestures communicate because they index words and phrases to objects and locations in the physical world (Glenberg and Robertson, 2000). Pointing gestures help listeners to make reference, especially when speech is ambiguous or degraded (Thompson and Massaro, 1994). From an embodied perspective, this phenomenon suggests that speakers' pointing gestures help listeners to index the referents that speakers intend. Thus, in communicative settings, pointing gestures affect listeners' reasoning because they help listeners grasp speakers' referential intentions.

Representational gestures also influence listeners' comprehension. There are at least two possible pathways by which this could occur. First, observing a speaker's representational gestures might guide listeners in constructing corresponding action simulations in their own minds (Alibali and Hostetter, 2011). When people observe others' actions, motor and premotor areas of their brains are activated in corresponding ways (Jeannerod, 2001; Rizzolatti, Fogassi, and Gallese, 2001; Wheaton, Thompson, Syngieniotis, Abbott, and Puce, 2004). Put simply, "our

motor system simulates under threshold the observed action in a strictly congruent fashion” (Fadiga, Craighero, and Olivier, 2005, p. 213). Because gestures are a form of action, the same principles presumably apply in observing gestures. If gestures manifest simulated actions and perceptual states, then observing gestures may guide listeners to generate corresponding simulations in their own minds. In this way, speakers’ representational gestures may help listeners to comprehend speakers’ semantic intentions.

Second, observing speaker’s gestures may encourage listeners to produce corresponding gestures themselves. That is, viewing a speaker’s gestures may elicit overt mimicry of those gestures, and those gestures may in turn affect reasoning. A similar mechanism has been proposed for understanding facial expressions of emotion (the Simulation of Smiles model; Niedenthal, Mermillod, Maringer, and Hess, 2010). According to this model, both mimicry and simulation contribute to perceivers’ understanding of different types of smiles. In a parallel fashion, we suggest that both overt gestural mimicry and covert simulation of corresponding actions contribute to listeners’ comprehension of speakers’ gestures.

Do listeners overtly mimic speakers’ gestures, either in silence during the speaker’s turn, or in their own subsequent turns? Indeed, such mimicry does occur. For example, children who received a math lesson in which the instructor gestured were themselves more likely to gesture when explaining math problems than children who received a similar lesson in which the instructor did not gesture (Cook and Goldin-Meadow, 2006). Moreover, children’s gestures tended to reproduce the form of the instructor’s gestures – thus, children mimicked the instructor’s gestures.

Gestural mimicry is also evident in other discourse contexts, including conversation and narrative (Kimbara, 2006; Lakoff and Núñez, 2001). Moreover, people produce similar gestures more frequently when they can see one another than when they cannot (Holler and Wilkin, 2011; Kimbara, 2008) – suggesting that gestural mimicry is purposeful, and not simply due to people using similar gestures when they talk about similar things. Holler and Wilkin (2011) argue that gestural mimicry fosters shared understanding between participants in dialogue, in some cases by presenting semantic information that aligns with what the other had expressed on a previous turn, and at other times by displaying “acceptance” or comprehension of the other’s communication.

However, despite evidence that gesture mimicry plays an important role in establishing shared understanding, overt mimicry of gestures seems unusual, rather than common. It is indeed rare to see listeners gesture when others are speaking; therefore, it seems likely that most of gesture’s contribution to comprehension comes from gesture guiding covert action simulations, or facilitating reference via indexing.

In sum, there are multiple reasons why speakers’ gestures may influence listeners’ comprehension, and consequently their reasoning (Hostetter, 2011). First, speakers’ gestures help listeners to index speakers’ utterances to the physical environment. Second, speakers’ gestures help listeners to construct simulations that align with those of the speakers. They may do so via two different pathways – by encouraging overt mimicry of gestural actions, or by guiding construction of appropriate simulations.

Conclusion

In this chapter, we have provided evidence for three broad claims regarding gesture and reasoning. First, we argued that gestures manifest embodied processes in reasoning. In line with the GSA framework, we argued that *representational gestures* derive from mental simulations of actions and perceptual states. When speakers express ideas based in simulations of actions and perceptual

states, they often produce gestures, and those gestures manifest the embodied nature of those ideas. Further, we argued that *pointing gestures* index objects and locations in the physical world. As such, pointing gestures provide evidence for the claim that cognition is grounded in the physical environment.

Second, we presented evidence that gesture plays a causal role in reasoning, and that it does so by highlighting perceptual and motor information, both in the environment and in people's mental simulations of tasks or scenes. We argued that gestures raise activation on perceptual and motor information, and therefore, when people produce gestures, they are more likely to incorporate such information into their reasoning and problem solving.

Finally, we argued that speakers' gestures affect listeners' reasoning. Speakers' gestures guide listeners' indexing of speakers' utterances to the physical environment. In addition, speakers' gestures may help listeners to construct simulations that align with speakers' simulations. This may occur via listeners' direct mimicry of speakers' gestures, or by listeners using information expressed in speakers' gestures to guide and constrain their mental simulations.

In sum, gestures offer researchers a valuable window on the embodied cognitive processes involved in reasoning. Moreover, as a form of action, gestures play a functional role in those processes, as well. It is becoming increasingly clear that gestures are more than simple "hand waving." As such, a deeper understanding of how and why people gesture is critical for scientific progress in understanding human reasoning.

References

- Alibali, M. W., and Hostetter, A. B. (2011). Mimicry and simulation in gesture comprehension. *Behavioral and Brain Sciences*, 33, 433–34. (Commentary on Niedenthal, Maringer, Mermillod, and Hess, 2010.)
- Alibali, M. W., and Kita, S. (2010). Gesture highlights perceptually present information for speakers. *Gesture*, 10(1), 3–28.
- Alibali, M. W., and Nathan, M. J. (2012). Embodiment in mathematics teaching and learning: Evidence from students' and teachers' gestures. *Journal of the Learning Sciences*, 21(2), 247–86.
- Alibali, M. W., Spencer, R. C., Knox, L., and Kita, S. (2011). Spontaneous gestures influence strategy choices in problem solving. *Psychological Science*, 22(9), 1138–44.
- Anderson, M. L. (2003). Embodied cognition: A field guide. *Artificial Intelligence*, 149(1), 91–130.
- Barsalou, L. W., Simmons, W. K., Barbey, A. K., and Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences*, 7(2), 84–91.
- Beilock, S. L., and Goldin-Meadow, S. (2010). Gesture changes thought by grounding it in action. *Psychological Science*, 21(11), 1605–10.
- Boncoddo, R., Dixon, J. A., and Kelley, E. (2010). The emergence of a novel representation from action: Evidence from preschoolers. *Developmental Science*, 13(2), 370–77.
- Butcher, C., Mylander, C., and Goldin-Meadow, S. (1991). Displaced communication in a self-styled gesture system: Pointing at the nonpresent. *Cognitive Development*, 6, 315–42.
- Catrambone, R., Craig, D. L., and Nersessian, N. J. (2006). The role of perceptually represented structure in analogical problem solving. *Memory and Cognition*, 34(5), 1126–32.
- Chu, M., and Kita, S. (2008). Spontaneous gestures during mental rotation tasks: Insights into the microdevelopment of the motor strategy. *Journal of Experimental Psychology: General*, 137(4), 706–23.
- (2011). The nature of gestures' beneficial role in spatial problem solving. *Journal of Experimental Psychology: General*, 140(1), 102–16.
- Cook, S. W., and Goldin-Meadow, S. (2006). The role of gesture in learning: Do children use their hands to change their minds? *Journal of Cognition and Development*, 7, 211–32.
- Cook, S. W., and Tanenhaus, M. K. (2009). Embodied communication: Speakers' gestures affect listeners' actions. *Cognition*, 113(1), 98–104.
- Cook, S. W., Yip, T. K., and Goldin-Meadow, S. (2010). Gesturing makes memories that last. *Journal of Memory and Language*, 63(4), 465–75.
- Duncker, K. (1945). On problem solving (L. S. Lees, Trans.) (Special issue). *Psychological Monographs*, 58(270).

- Fadiga, L., Craighero, L., and Olivier, E. (2005). Human motor cortex excitability during the perception of others' action. *Current Opinion in Neurobiology*, 15(2), 213–18.
- Fischer, M. H., and Zwaan, R. A. (2008). Embodied language: A review of the role of the motor system in language comprehension. *Quarterly Journal of Experimental Psychology*, 61(6), 825–50.
- Glenberg, A. M., and Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, 9, 558–65.
- Glenberg, A. M., and Robertson, D. A. (2000). Symbol grounding and meaning: A comparison of high-dimensional and embodied theories of meaning. *Journal of Memory and Language*, 43, 379–401.
- Glenberg, A. M., Sato, M., Cattaneo, L., Riggio, L., Palumbo, D., and Buccino, G. (2008). Processing abstract language modulates motor system activity. *Quarterly Journal of Experimental Psychology*, 61(6), 905–19.
- Goldin-Meadow, S. (2003). *Hearing gesture: How our hands help us think*. Cambridge, MA: Harvard University Press.
- Goldin-Meadow, S., and Beilock, S. L. (2010). Action's influence on thought: The case of gesture. *Perspectives on Psychological Science*, 5(6), 664–74.
- Hauk, O., Johnsrude, I., and Pulvermüller, F. (2004). Somatotopic representation of action words in human motor and premotor cortex. *Neuron*, 41, 301–7.
- Holler, J., and Wilkin, K. (2011). Co-speech gesture mimicry in the process of collaborative referring during face-to-face dialogue. *Journal of Nonverbal Behavior*, 35(2), 133–53.
- Hostetter, A. B. (2011). When do gestures communicate? A meta-analysis. *Psychological Bulletin*, 137(2), 297–315.
- Hostetter, A. B., and Alibali, M. W. (2008). Visible embodiment: Gestures as simulated action. *Psychonomic Bulletin & Review*, 15(3), 495–514.
- (2010). Language, gesture, action! A test of the Gesture as Simulated Action framework. *Journal of Memory and Language*, 63, 245–57.
- Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage*, 14, S103–9.
- Kimbara, I. (2006). On gestural mimicry. *Gesture*, 6(1), 39–61.
- (2008). Gesture form convergence in joint description. *Journal of Nonverbal Behavior*, 32(2), 123–31.
- Kita, S., and Özyürek, A. (2003). What does cross-linguistic variation in semantic coordination of speech and gesture reveal? Evidence for an interface representation of spatial thinking and speaking. *Journal of Memory and Language*, 48, 16–32.
- Lakoff, G., and Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.
- Lakoff, G., and Núñez, R. (2001). *Where mathematics comes from: How the embodied mind brings mathematics into being*. New York: Basic Books.
- Maier, N. R. F. (1931). Reasoning in humans, II: The solution of a problem and its appearance in consciousness. *Journal of Comparative Psychology*, 12, 181–94.
- Marghetis, T., Bergen, B., and Núñez, R. (2012). Metaphorical conceptualization of arithmetic: Evidence in gesture of the flexible deployment of complementary construals of abstract arithmetic. Paper presented at the Fourth Annual Meeting of the UK Cognitive Linguistics Association, London, July.
- McNeill, D. (1992). *Hand and mind: What gestures reveal about thought*. Chicago: University of Chicago Press.
- (2005). *Gesture and thought*. Chicago: University of Chicago Press.
- McNeill, D., Quek, F., McCullough, K. E., Duncan, S., Furuyama, N., Bryll, R., et al. (2001). Catchments, prosody, and discourse. *Gesture*, 1(1), 9–33.
- Niedenthal, P. M., Mermillod, M., Maringer, M., and Hess, U. (2010). The Simulation of Smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *Behavioral and Brain Sciences*, 33, 417–80.
- Rizzolatti, G., Fogassi, L., and Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*, 2, 661–70.
- Roth, W. M. (2002). From action to discourse: The bridging function of gestures. *Cognitive Systems Research*, 3, 535–54.
- Shapiro, L. (2011). *Embodied cognition*. New York, NY: Routledge.
- Singer, M. A., Radinsky, J., and Goldman, S. R. (2008). The role of gesture in meaning construction. *Discourse Processes*, 45, 365–86.
- Thomas, L. E., and Lleras, A. (2007). Moving eyes and moving thought: On the spatial compatibility between eye movements and cognition. *Psychonomic Bulletin & Review*, 14(4), 663–68.

- (2009). Swinging into thought: Directed movement guides insight in problem solving. *Psychonomic Bulletin & Review*, 16(4), 719–23.
- Thompson, L. A., and Massaro, D. W. (1994). Children's integration of speech and pointing gestures in comprehension. *Journal of Experimental Child Psychology*, 57, 327–54.
- Wesp, R., Hess, J., Keutmann, D., and Wheaton, K. (2001). Gestures maintain spatial imagery. *American Journal of Psychology*, 114, 591–600.
- Wheaton, K. J., Thompson, J. C., Syngeniotis, A., Abbott, D. F., and Puce, A. (2004). Viewing the motion of human body parts activates different regions of premotor, temporal, and parietal cortex. *NeuroImage*, 22(1), 277–88.
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, 9, 625–36.

16

THE EMBODIED DYNAMICS OF PROBLEM SOLVING

New structure from multiscale interactions

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Problem solving has been a rich area for psychology. Nearly all major cognitive phenomena occur in the context of problem solving, including memory search (Hélie and Sun, 2010), analogical mapping (Gick and Holyoak, 1980), reasoning (Thibodeau and Boroditsky, 2011), association (Grabner *et al.*, 2009), abductive inference (Langley, Laird, and Rogers, 2009), and priming (Slepian, Weisbuch, Rutchick, Newman, and Ambady, 2010), as well as many social phenomena, such as group facilitation (Liker and Bókonyi, 2009) and inhibition (Diehl and Stroebe, 1987) effects. In a sense, problem solving provides us with a microcosm of the key issue for psychology, “How does an organism successfully engage in goal-directed action?” Indeed, if we had a fully worked out theory of problem solving, it would provide a foundation on which to build theories of cognition. Currently, however, psychology and cognitive science place little emphasis on problem solving as a major area in the field, although posing problems to organisms, typically humans, is the stock-in-trade of experimental psychologists. Most studies in psychology pose a problem to their participants, in the form of task instructions and constraints, with the hope that participants will solve the problem using the processes the researcher wishes to study. Missing from current practice is a theory (or even a reasonable hypothesis) about how an organism could configure itself into some novel spatio-temporal structure in a way that accomplishes a novel task. Of course, we recognize that experimental tasks might be considered graded in terms of their novelty at a particular moment in time. For example, recalling a list of words might be analogous to recalling items on a shopping list and thus weakly novel. Naming the color of ink in which words are written, while trying not to read the words (the classic “Stroop” task), might be considered somewhat more strongly novel. At the far end of this continuum, might be tasks that are explicitly intended to require an innovative solution, such as the mutilated checkerboard problem (Kaplan and Simon, 1990) or traveling salesman problem (Applegate, Bixby, Chvatal, and Cook, 2011).

Early giants in the field, such as Köhler (1947) and Duncker (1945), appreciated that an organism’s ability to generate innovative solutions in the face of novel problems was a deep theoretical issue. Indeed, as we will argue below, taking this aspect of problem solving seriously provides a powerful constraint on how we should conceive of cognition, in general. Consider,

for example, how an organism could know, in advance of actually doing it, that configuring itself in a particular way would allow it to obtain a desired goal. Organisms from all five kingdoms are capable of this, but for now let us take the familiar example of a primate staring at a banana that is suspended from the ceiling, well out of reach. After trying out a few behaviors, such as jumping and climbing on objects, the primate stacks some nearby boxes, creating a platform from which he or she can reach the banana (Köhler, 1956). Let us stipulate that, because this primate has been reared in controlled conditions, we can be quite certain of the novelty of the problem and the solution. The primate in this example has generated a new structure, the complex behavior of stacking the boxes and climbing upon them, in the service of a goal. The question is: how could a theory of cognition explain such an event?

First, we consider the ability of computationalism-representationalism to address novel cognitive structures. We then discuss embodied cognition as an emerging position that may provide an account of novelty in cognition. Finally, we illustrate how such an approach might begin to be fleshed out using examples for our own recent work.

Computation over representations

Clearly, the dominant theoretical framework for cognition assumes that cognition is the processing of “information,” and that information processing must be computations over representations (Fodor, 1981; Newell, 1994). The assumptions of this framework are so deeply embedded in how cognitive scientists and psychologists currently think about cognition that it often appears that they are unaware that computationalism-representationalism (henceforth, CR) is actually a theoretical position, not a self-evident fact. At the risk of treading too-well-worn paths, recall that CR takes the strong position that representations are internal states of arbitrary form that stand in some relation to external events in the world, and that these states are operated on by a set of rules. The output of this process yields another symbol (or symbols) the meaning of which is relevant to the organism, e.g. “It’s a frog,” “Scratch your left ear,” “She’s not listening,” etc. It is important to point out here that if one takes CR as a theoretical approach to explaining cognition, then the whole theory has to be fleshed out in representations and computations. For example, one cannot insert an intelligent agent at the back end of the process that interprets the symbol, provides the necessary background knowledge, decides what actions to take, or otherwise provides the intelligent, goal-directed behavior we set out to explain (Dennett, 1981).

One of the many limitations of CR is that the symbols and the rules are fixed. That is, there’s no natural way for the system to generate new symbols or new rules. No matter how many times a rule is invoked or a symbol used as input or output, novel rules and representations do not occur. This point is easy to appreciate, if one imagines the steps taken in the operation of a Turing machine: advance tape, read symbol, write symbol, advance tape. These operations are all there is to this form of computation. The machine can only read-write symbols it already knows and only execute rules it already has stored. Indeed, it is reasonable to think of computation as a highly efficient method of expressing what is already known (and encoded into the computing system).

Two major escape hatches might save CR from this seeming incompatibility with the facts of cognition. First, one might propose that the system actually contains all the rules it will ever use, but that they unfold over the life of the organism through some unspecified developmental process. Novelty here is just a mirage. The system already knows everything there is to know, but rolls out that knowledge when the time is right. This would clearly be a miracle of very high order. But even if one accepts that biology and evolution might be capable of pulling off something so extraordinary, it seems obvious that this explanation only works for objects and situations with

an evolutionary history. Humans, for example, both create and adapt to cultural artifacts (e.g. golf clubs, cars, keyboards), objects that have no history on an evolutionary timescale. Thus, our abilities to configure ourselves into a biomechanically efficient striker of a tiny white ball or a non-self-propelled controller of a complicated high-speed machine are clearly not going to be explainable this way.

The second way one might attempt to save CR from the conundrum of novelty is to suggest that the computational system essentially operates on itself (Goldberg and Holland, 1988). This account proposes that there exists a class of symbols, call them second-order symbols, which stand in relation to the system's own internal rules or parts of those rules. For example, a rule such as "if *C* is true, then *P*" might be represented by two second-order symbols, *X* which would stand for phrase "if *C* is true," and *Y* which would stand for "then *P*." These second-order symbols would then be manipulated by their own set of rules. The key role of these rules would be to recombine the second-order symbols into new combinations, thus allowing the system to invent new rules. Thus, the system might make a combination that specifies, "if *C* is true, then *Q*." While such a modification of CR is plausible, it is hopelessly underpowered. The size of the set of possible combinations is just the product of the number of unique phrases of each type. The second-order rules generate novel first-order rules, but from a limited and completely prescribed set.

Note that this approach cannot be expanded to generate new symbols (i.e. representations) that stand in relation to the objects, events, etc., in the environment. The reason is easy to appreciate. CR systems are only in touch with the environment through their current set of symbols. All elements in the environment that are not encoded by those symbols are undetectable for that system. They literally have no means of entry. So, in the absence of a special front-end, an explicitly non-CR front-end that knows about the environment in some other way, CR systems cannot generate new symbols. This point begins to sail close to the now standard (and quite devastating) critique of CR that emphasizes its failures in the realm of semantics (Bickhard and Terveen, 1996). While we appreciate the force of those arguments, here we have focused briefly on issues that bear more especially on the generation of new structure.

Embodied cognition

Unlike CR, embodied cognition does not yet have a rigorous definition, and thus evaluating its potential requires some speculation about what exactly it entails. At a minimum, embodied cognition proposes that the states and actions of the body play a causal role in processes that are traditionally considered cognitive.

Embodied cognition has the potential to offer a serious alternative to CR. However, realizing this potential requires a radical rethinking of the nature of cognition. If embodied cognition is to move the field beyond its current state, it must embrace the deep implications of cognition being a physical (i.e. embodied) system. Attempting to slide embodiment beneath CR, as a grounding for representations, will simply inherit all the problems of CR while resolving none of them.

What then are the deep implications of cognition being a physical system? We propose the following fundamental properties of biological systems as an initial starting place for understanding cognition.

Dissipative structures

All organisms, including humans, are ensembles of dissipative structures (Kondepudi, 2012). Dissipative structures are self-organizing systems that form and persist in response to the flow of

energy and matter. That is, they emerge to degrade energy and their survival continually requires energy degradation (Kondepudi, 2008). That biological entities are dissipative structures is non-controversial, although the theory has been primarily developed in physico-chemical systems. Importantly, dissipative structures have a number of properties that help get a theory of cognition off the ground. First, they occur spontaneously in living and non-living systems, so their origin is cashed out from first principles, that is, thermodynamic laws. One need not license their existence through appeals to special processes or hidden agents. Second, dissipative structures are exquisitely sensitive to changes in their environments. Any change in circumstance that changes the flow through the structure can have consequences for the whole structure, including generating new structures. Thus, explaining how a system can rapidly and seamlessly adjust to changes in the environment becomes a question of tracking how exogenous energy fluctuations impact the flow through the system. Inherently intractable issues such as “encoding,” “sensory integration,” and the like are rendered nugatory in this framework. Third, dissipative structures exhibit a rudimentary form of end-directedness; they form such that their spatio-temporal properties degrade energy and, perhaps, maximize the rate of entropy production. Thus, the question of how inert matter becomes active is answered directly by the theory of dissipative structures.

Nested, multiscale systems

The ensembles of dissipative structures that constitute organisms are organized across a wide range of spatio-temporal scales. These scales are nested such that smaller-scale structures comprise larger scales. In complex biological systems, the number of scales is not known and likely changes over time. Both the spatial structures (i.e. morphology) and temporal structures (i.e. behaviors) that are typically the focus of research in biology and psychology are embedded in the activity of the other scales of the system. Embedded here means that there are causal dependencies amongst structures at different scales. A class of formalisms has been developed to express these multiscale relations in complex systems in physics and related fields (Lovejoy and Schertzer, 2013). It is important to keep in mind that our identification of the behavior (or aspect of morphology) in which we are interested, say the discovery of a new problem-solving strategy, is the application of a particular measurement frame on a continuous and extremely heterogeneous system. The act of measuring the system tempts us not only to reify the behavior, but also to treat it as if it were now a component part in a mechanical system. In psychology and cognitive science, this usually involves casting the behavior as a player on the stage of the general linear model, in which exogenous causes push and pull on non-causal outcome variables. However, the proper metaphysics for understanding biological behavior is dictated by the multiscale, nested nature of the system that produced the behavior, not the convenience and familiarity of the metaphysics of machines.

Commerce in energy and matter

Effects in physical systems, including those within biology, must be understood in terms of the flow of energy and matter. If we are to have an embodied cognition, then it too will require that interactions are the sole result of energy consumption, and thus the quantities we measure should relate directly to energy consumption. This provides a common currency across all scales of the system and environment, as well as explicit connections to thermodynamic laws. It is worth noting here that taking energy (or another thermodynamic variable) as a primary measure does not deny the ultimate goal of psychology and cognitive science to explain relatively macro-scale patterns of behavior. Rather, we propose that these patterns of behavior are the result of thermodynamic (i.e. energy-consuming) processes.

Rule induction in card sorting

Among the many amazing properties of human problem solvers is the seeming ability to detect regularities embedded in sequences of temporal events. From our theoretical perspective, when any organism detects a regularity (i.e. a “rule”), it has reorganized itself such that it is now attuned to a new pattern of variation in the environment. This is a substantial and non-trivial event for the system, and thus we should be able to see evidence for it in the multiscale behavior of the system.

To test this overarching hypothesis, we asked college-age participants to perform a reduced version of the Wisconsin Card Sort Test (WCST) (Grant and Berg, 1948). Participants were asked to sort cards into four categories, each defined by a guide card. After they placed each card, the experimenter provided them with feedback about whether or not that placement was correct. Participants had to induce the correct sorting rule for each of five trials. (In the classic WCST, but not here, the rule also changes within trial). An example of this simple set-up is shown in Figure 16.1.

As a comparison condition, we asked a second group of participants to sort cards according to the same rules, but in this condition the rules were stated explicitly. A new rule was given to the participants (as was the initial rule) at the start of each trial. Thus, this group sorted cards according to the same rules, but did not have to induce the rules. We call this the “explicit” condition to denote the explicit stating of the rules; and the set-up described above, the “induction” condition (see Anastas, Stephen, and Dixon [2011] for details).

For both conditions, we tracked the motion of the participant’s dominant hand (i.e. the hand used to sort the cards) at a high sampling rate (60 hertz) and with considerable precision (on the millimeter scale). We used the time series of the motion data to quantify multiscale activity of the system.

A few words are probably in order here about why we think the motion of the hand tells us about activity of the cognitive system with respect to this task. Consider that inferring that a

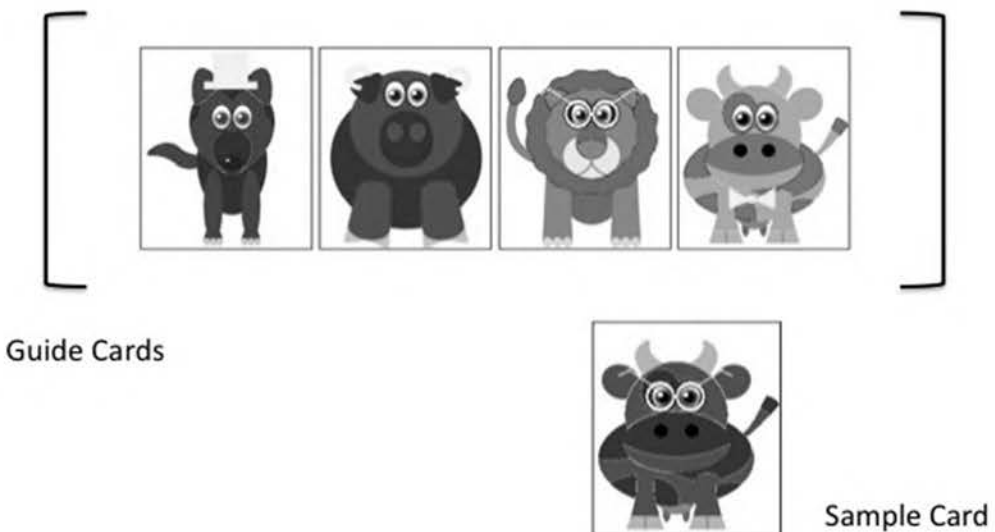


Figure 16.1 Card-sorting task. A simple card sorting task in which children are asked to sort along one dimension (e.g. type of animal), while ignoring the other dimensions.

participant has a “rule” involves applying a particular measurement frame to the pattern of motions he or she generates, relative to the problem context. Relatively macro-scale temporal relations in the participant’s motions are taken as evidence of having acquired the rule. While it is tempting to talk about “rules” and other cognitive structures as if they existed as disembodied entities, their measurement in scientific practice requires an instantiation in the physical world. (One might also note that a commitment to materialism makes a parallel argument for the physical instantiation of rules.) If rules are then to be embodied entities that are produced by real, multiscale physical structures, they should show interesting micro-scale behavior, especially during their formation. Because hand motions are intrinsic to the instantiation of the rules in the present task, they should provide a quantitative window onto the relevant system activity.

A rejoinder to this argument, it should be noted, is that hand motions are run by the motor system, and that a different system is in charge of cognitive structures such as rules. This second system tells the motor system what to do, in general terms, and the motor system works out the details. Implicit in this description of two systems (rather than one) is the idea that motor processes and cognitive processes are insulated from each other. The systems communicate over some channel but do their work independently. This strong architectural assumption, an implication of Simon’s near-decomposability thesis (Simon, 1962), is rarely tested, despite the fact that it is the essential licensure for all component approaches to cognition.

There are a few ways to empirically evaluate the component assumption. Some involve quite quantitatively advanced methods, usually in the realm of time-series analysis, such as iterative amplitude adjusted Fourier transform (Ihlen and Vereijken, 2010). Others are more pragmatic in that they simply ask whether the component that is proposed to be causally downstream (e.g. motor) is related to upstream components (e.g. cognitive) in unexpected ways. In a sense, most of the surprising effects in embodied cognition are of this latter type. We have examined both types of evidence for the card-sorting data. Although we focus on the latter type here, we note that more quantitatively advanced methods strongly suggest that card-sorting is not the product of a component-dominant process (Stephen, Anastas, and Dixon, 2012).

To explore the relationships between the microstructure of the motion of the hands and the phenomenon of induction, we briefly and non-technically consider a quantitative measure of multiscale activity, because some such measures are necessary to tell the rest of the story. The motion data obtained during each participant’s card sorting contain a remarkable amount of information about the activity of the system during the task. One analysis of interest asks how the activity of the system is distributed over temporal scales. Physical systems that are composed of many interacting spatio-temporal scales will show a systematic relationship between temporal scale (i.e. the length of time over which the measurement is taken) and the degree of activity. We used detrended fluctuation analysis (DFA) (Peng *et al.*, 1994) to estimate the relationship between temporal scale and activity. This relationship is typically (and testably) a power law, quantified in DFA as a Hurst exponent (H). Values of H near 1 are consistent with long-term correlations in the time series, and have been taken as an index of the degree to which the system is “poised” to respond to changes. Not too long ago, researchers began to find $H \sim 1$ in a wide variety biological domains, suggesting that many processes in biology and psychology were not only poised to respond to changes, but appear to return repeatedly to that poised state (Bak, 1999). A related body of work shows that as a complex system approaches a structural or functional change, it goes to a poised (or “critical”) state, showing properties much like a phase transition (Hinrichsen, 2006).

In the card-sorting task, the motion data from both the induction and explicit conditions had average Hurst exponents that suggested long-term correlations in the data. More importantly, we predicted that participants in the induction condition (who had to discover the rule) would

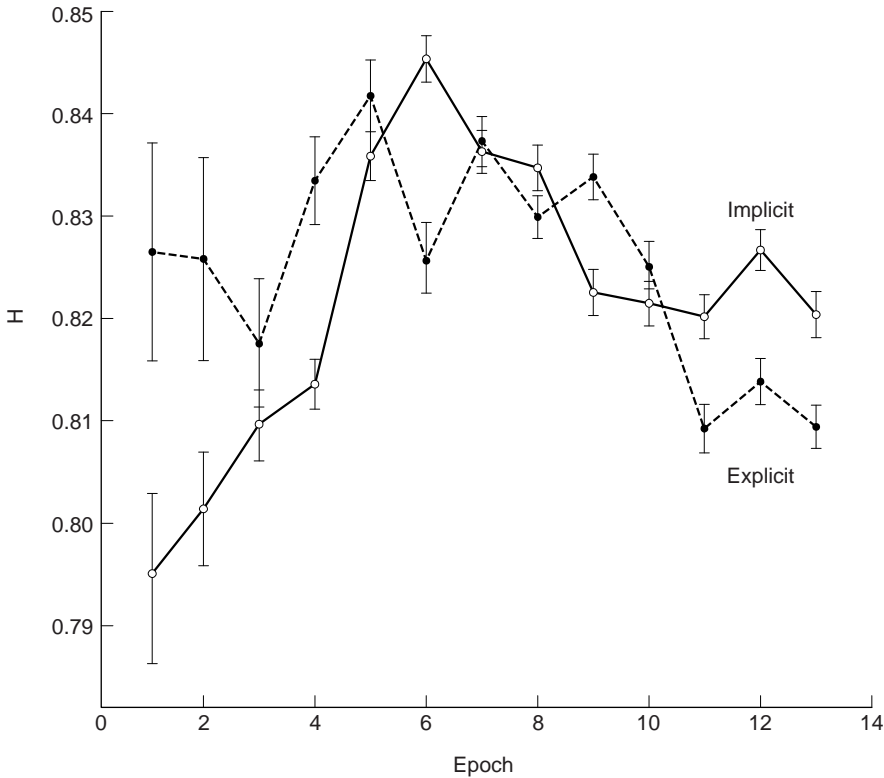


Figure 16.2 Hurst exponents over time during card sorting. The Hurst exponents (H) are shown as a function of epoch (time), with separate curves for the “implicit” and “explicit” rule conditions. Errors bars show 1 standard error of the mean.

show an pattern of increase and decrease in their Hurst exponents, indicative of the system becoming poised for a change (increasing H), and then settling into a stable regime (decreasing H). We also predicted that participants in the explicit condition (who were given the rules) would show a decrease in their Hurst exponents as they settled into a stable organization with the given rule. Figure 16.2 shows the average Hurst exponents for both conditions as a function of time (expressed as epochs; epochs are about 13 seconds in duration). Both these predictions were confirmed: the induction condition showed a strong peak in the Hurst exponent, and the explicit condition showed an overall decrease.

Note that in both these conditions participants were, from a motor perspective, doing much the same thing: sorting cards into four piles. The speed of their sorting motions, the duration of the trials, and a variety of other factors do not significantly differ between conditions, nor do they add predictive power to statistical models of the Hurst-exponent trajectories. The difference between the time series generated in these two conditions is not reducible to some macro-scale difference. Rather, the difference in the over-time trajectories of the Hurst exponents is consistent with the hypothesis that rule induction is an instance of self-organization in a multiscale system. The interactions across scales increase in the induction condition, allowing the system to reach a novel rule, and then decrease as the system stabilizes around that rule. Likewise, in the explicit condition, in which no discovery is necessary, the system just stabilizes as it repeatedly

instantiates the rule. “Rule” here, we should emphasize, is a shorthand way of describing a particular, and quite complex, spatio-temporal organization of the system, rather than a simple conditional statement (e.g. “Put the card in the pile that matches on color”). While such a statement is enough to get a participant started sorting, his or her system still must organize to the many constraints of the task, such as spatial positions, variations across individual cards, etc. The rule that the system learns is the amalgamation of all the relevant task constraints.

Gear-system problems

While the card-sorting tasks have the virtue of being easy to manipulate and control, and thus amenable to experimentation, they are quite simple relative to many of the classic paradigms in problem solving. In other work, we have employed a more complex task in which participants spontaneously discover new, higher-order rules without being told that such a rule exists (Dixon and Bangert, 2002; Stephen, Dixon, and Isenhower, 2009). This paradigm has the virtue of being closer to the type of discovery that occurs in many real-world problem situations. In this task, participants are shown a set of interlocking gears. They are asked to predict the turning direction of the final gear in the series, the “target” gear, given the turning direction of the “driving” gear, the gear that provides the force to the system (see Figure 16.3). Participants are asked to solve a

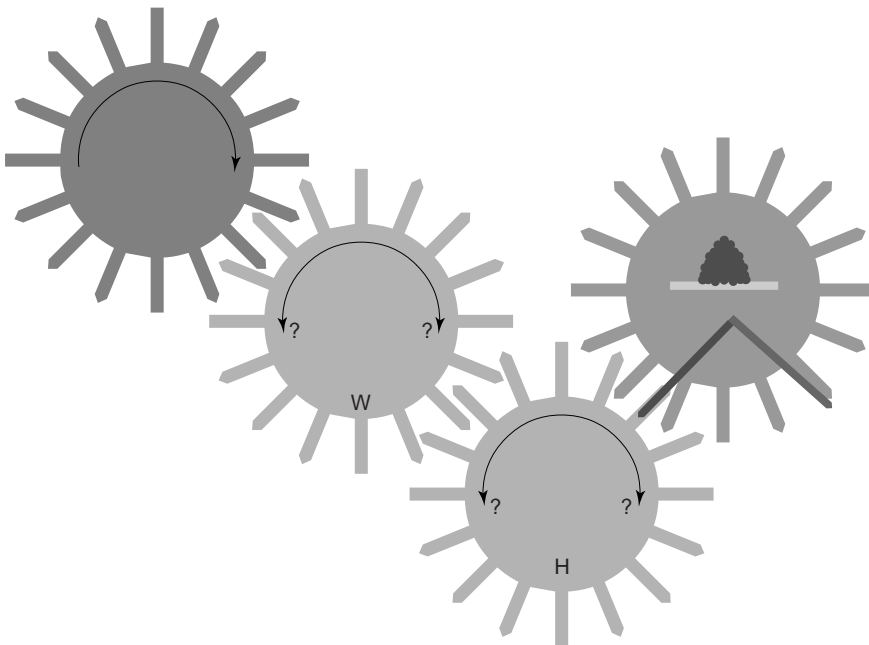


Figure 16.3 An example gear-system problem. Participants were asked to predict the turning direction of the target gear, on the far right, given the turning direction of the driving gear on the far left (clockwise in this example). The intermediate gears were labeled (here, “W” and “H”) to facilitate participants talking about them. The task is embedded in a game about a train race. The object of each trial in the game is to position one’s train beneath the target gear so as to catch the coal as it slides off. Note that only the target gear is ever seen to move; the other gears are occluded before the gears turn.

variety of problems of this type. The spatial configuration and number of gears in the system varies across problems. The vast majority of college-age participants initially solve this problem by manually simulating the movement of each gear in succession. That is, they trace their finger around the outer edge of each gear, starting with the driving gear, and ending at the target gear (which then gives the solution). We call this strategy “force tracing.” The interesting phenomenon here is that, after using the force-tracing strategy some number of times, the majority of participants spontaneously discover (and employ) a higher-order relation to solve the gear problems. Specifically, they discover that adjacent gears alternate directions, and thus solve the problems by sequentially categorizing each gear as “clockwise” or “counterclockwise,” a strategy we call “alternation.”

Just as in the card-sorting task, we tracked the motion of each participant’s hand while they solved the problems. For each participant, we analyzed the motion data on all the trials prior to their discovery of alternation (which were nearly all solved via force tracing). For participants who discovered alternation, we found that the power-law exponent increased to a peak, and then decreased immediately before discovery. Participants who did not discover alternation (i.e. kept using force tracing) showed a much shallower increase in the power-law exponent (Stephen and Dixon, 2009). Figure 16.4 shows the data averaged over participants. The top panel shows the power-law exponents aligned by trial number. As can be seen in the figure, the exponent increases more dramatically for participants who discovered alternation. The lower panel shows the power-law exponent for discoverers only, aligned on the far left on the trial in which they discovered alternation. The trial labeled “-1” is immediately prior to discovery, the trial labeled “-2” is two trials prior to discovery, etc. The figure shows that just prior to discovery there is a decrease in the power-law exponent. Both these effects were confirmed in growth curve analyses.

Conclusions

We have argued that the dominant approach to cognition, CR, cannot handle the phenomenon of new structure, a fundamental aspect of the problem-solving behavior exhibited by humans and other organisms. Embodied cognition has the potential to provide an account of how new structures emerge. The implications of this account could radically reshape how we understand cognition. We propose that such an account must be grounded in thermodynamic laws, while capitalizing on what is already known about how those laws manifest themselves in complex, heterogeneous systems. The work we have reviewed above takes some initial steps in this direction, addressing the phenomenon of new macroscopic cognitive structure as a phase transition. Phase transitions are well understood theoretically, and have been broadly demonstrated empirically in a wide variety of systems (e.g. Cortet, Chiffaudel, Daviaud, and Dubrulle, 2010). Our work shows that the formation of new cognitive structures shows the same signatures as in other embodied, physical systems. That is, an increase in fluctuations as the transition point approaches, indexed by an increase in H (and followed by a decrease in those fluctuations). While it is, of course, possible to create long-term correlated time series using linear methods (and thus consistent with the near-decomposability assumption), it is not clear how such an approach would explain the observed pattern of changes in H . We note that our work shows that these patterns can be experimentally manipulated, as well as observed in spontaneous behavior. Finally, we note that, in our view, embodied cognition is poised at a critical juncture. It can become a side show in the CR cognition circus, an exhibit of somewhat perplexing and bemusing phenomena that run counter to expectation. Or by embracing the deep implications of its commitment to the physical, it can become a truly new approach to cognition.

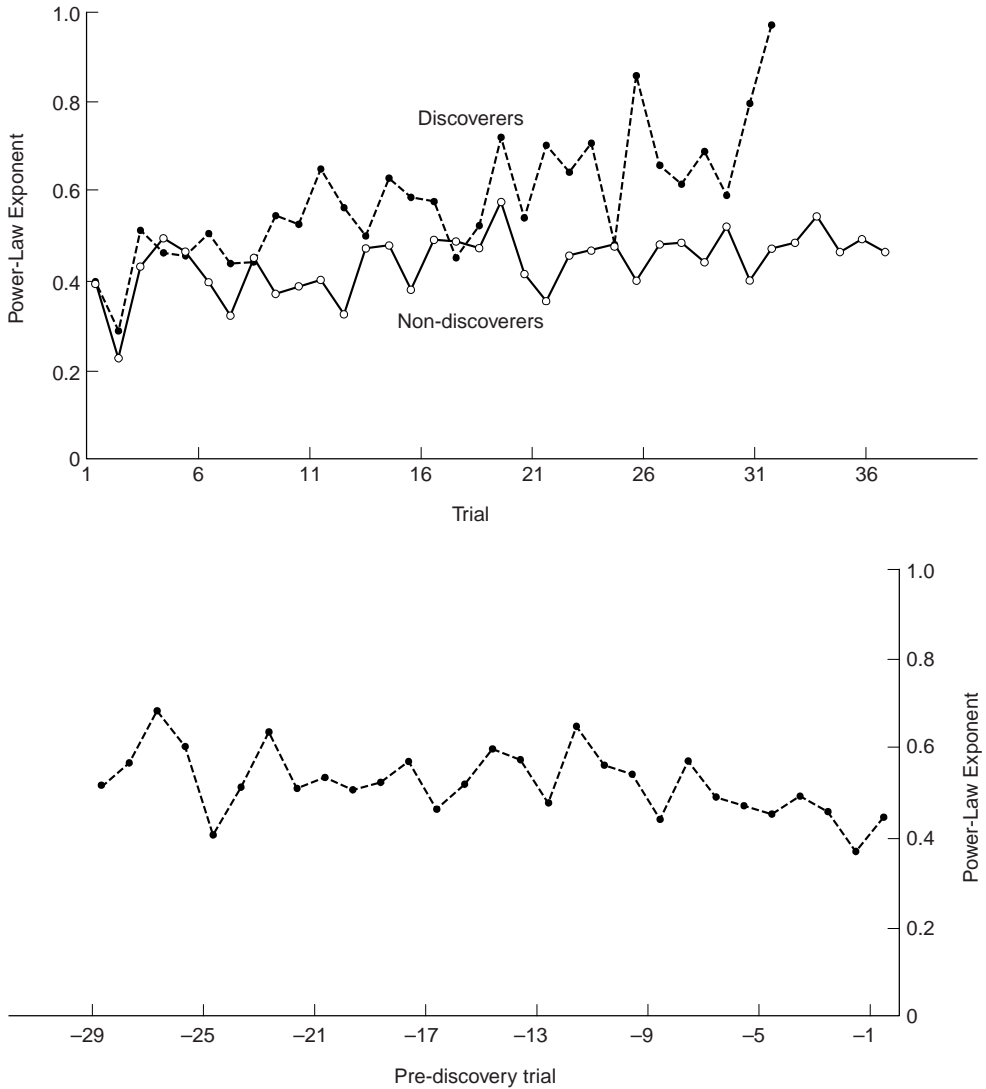


Figure 16.4 Power-law exponents over trials for the gear task. The top panel shows the power-law exponent as a function of trials for participants who discovered alternation, “Discoverers,” and participants who did not discover alternation, “Non-discoverers”. The lower panel again shows the power-law exponents of “Discoverers,” but now the bottom-most point is aligned on the trial on which they discovered alternation. Thus, the lower panel shows the average power-law behavior as participants approach discovery.

References

- Anastas, J. R., Stephen, D. G., and Dixon, J. A. (2011). The scaling behavior of hand motions reveals self-organization during an executive function task. *Physica A: Statistical Mechanics and its Applications*, 390(9), 1539–45.
- Applegate, D. L., Bixby, R. E., Chvatal, V., and Cook, W. J. (2011). *The traveling salesman problem: A computational study*. Princeton: Princeton University Press.
- Bak, P. (1999). *How nature works: The science of self-organized criticality*. New York: Springer.

- Bickhard, M. H., and Terveen, L. (1996). *Foundational issues in artificial intelligence and cognitive science: Impasse and solution*. Amsterdam: Elsevier.
- Cortet, P.-P., Chiffaudel, A., Daviaud, F., and Dubrulle, B. (2010). Experimental evidence of a phase transition in a closed turbulent flow. *Physical Review Letters*, 105, 214501.
- Dennett, D. C. (1981). *Brainstorms: Philosophical essays on mind and psychology*. Repr. ed. Cambridge, MA: MIT Press.
- Diehl, M., and Stroebe, W. (1987). Productivity loss in brainstorming groups: Toward the solution of a riddle. *Journal of Personality and Social Psychology*, 53(3), 497–509.
- Dixon, J. A., and Bangert, A. S. (2002). The prehistory of discovery: Precursors of representational change in solving gear system problems. *Developmental Psychology*, 38(6), 918–33.
- Duncker, K. (1945). On problem-solving (L. S. Lees, Trans.) (Special issue). *Psychological Monographs*, 58(270).
- Fodor, J. A. (1981). *The mind-body problem*. New York: W. H. Freeman.
- Gick, M. L., and Holyoak, K. J. (1980). Analogical problem solving. *Cognitive Psychology*, 12(3), 306–55.
- Goldberg, D. E., and Holland, J. H. (1988). Genetic algorithms and machine learning. *Machine Learning*, 3(2), 95–99.
- Grabner, R. H., Ansari, D., Koschutnig, K., Reishofer, G., Ebner, F., and Neuper, C. (2009). To retrieve or to calculate? Left angular gyrus mediates the retrieval of arithmetic facts during problem solving. *Neuropsychologia*, 47(2), 604–8.
- Grant, D. A., and Berg, E. (1948). A behavioral analysis of degree of reinforcement and ease of shifting to new responses in a Weigl-type card-sorting problem. *Journal of Experimental Psychology*, 38(4), 404–11.
- Hélie, S., and Sun, R. (2010). Incubation, insight, and creative problem solving: A unified theory and a connectionist model. *Psychological Review*, 117(3), 994–1024.
- Hinrichsen, H. (2006). Non-equilibrium phase transitions. *Physica A: Statistical Mechanics and Its Applications*, 369(1), 1–28.
- Ihlen, E. A. F., and Vereijken, B. (2010). Interaction-dominant dynamics in human cognition: Beyond 1/f α fluctuation. *Journal of Experimental Psychology: General*, 139(3), 436.
- Kaplan, C. A., and Simon, H. A. (1990). In search of insight. *Cognitive Psychology*, 22(3), 374–419.
- Köhler, W. (1947). *Gestalt psychology: An introduction to new concepts in modern psychology*. New York: Liveright Publishing.
- (1956). *The mentality of apes*. New York: Vintage Books.
- Kondepudi, D. (2008). *Introduction to modern thermodynamics*. Chichester, West Sussex: Wiley.
- (2012). Self-organization, entropy production, and physical intelligence. *Ecological Psychology*, 24(1), 33–45.
- Langley, P., Laird, J. E., and Rogers, S. (2009). Cognitive architectures: Research issues and challenges. *Cognitive Systems Research*, 10(2), 141–60.
- Liker, A., and Bókony, V. (2009). Larger groups are more successful in innovative problem solving in house sparrows. *Proceedings of the National Academy of Sciences of the United States of America*, 106(19), 7893–98.
- Lovejoy, S., and Schertzer, D. (2013). *The Weather and Climate: Emergent laws and multifractal cascades*. Cambridge: Cambridge University Press.
- Newell, A. (1994). *Unified theories of cognition*. Cambridge, MA: Harvard University Press.
- Peng, C. K., Buldyrev, S. V., Havlin, S., Simons, M., Stanley, H. E., and Goldberger, A. L. (1994). Mosaic organization of DNA nucleotides. *Physical Review E*, 49(2), 1685–89.
- Simon, H. A. (1962). The architecture of complexity. *Proceedings of the American Philosophical Society*, 106(6), 467–82.
- Slepian, M. L., Weisbuch, M., Rutchick, A. M., Newman, L. S., and Ambady, N. (2010). Shedding light on insight: Priming bright ideas. *Journal of Experimental Social Psychology*, 46(4), 696–700.
- Stephen, D. G., Anastas, J. R., and Dixon, J. A. (2012). Scaling in cognitive performance reflects multiplicative multifractal cascade dynamics. *Frontiers in Physiology*, 3(102).
- Stephen, D. G., and Dixon, J. A. (2009). The self-organization of insight: Entropy and power laws in problem solving. *Journal of Problem Solving*, 2(1), 72–101.
- Stephen, D. G., Dixon, J. A., and Isenhower, R. W. (2009). Dynamics of representational change: Entropy, action, and cognition. *Journal of Experimental Psychology: Human Perception and Performance*, 35(6), 1811–32.
- Thibodeau, P. H., and Boroditsky, L. (2011). Metaphors we think with: The role of metaphor in reasoning. *PLoS One*, 6(2), e16782.

GROUNDED MATHEMATICAL REASONING

Mitchell J. Nathan

Introduction

Galileo said, “[the universe] cannot be read until we have learnt the language and become familiar with the characters in which it is written. It is written in mathematical language, and the letters are triangles, circles and other geometrical figures, without which means it is humanly impossible to comprehend a single word.” How then, are we to comprehend mathematics itself? Grounded cognition provides an account.

Grounded cognition, notes Barsalou (2008, p. 619), explores the assumption that intellectual behavior “is typically grounded in multiple ways, including simulations, situated action, and, on occasion, bodily states.” When body states and body-based resources are central to these accounts of intellectual behavior, scholars typically use the more restricted term, *embodied cognition*. Grounded cognition, the more general term, is often contrasted with models of cognition that are based primarily on processes and structures composed of symbol systems that are abstract, amodal, and arbitrary (also called “AAA symbols”; Glenberg, Gutierrez, Levin, Japuntich, and Kaschak, 2004), because the symbols are non-concrete, make no reference to physical or sensory modalities, and serve their representational roles through arbitrary mappings between the symbols and the phenomena to which they refer. Examples of models based on AAA symbols include feature lists, semantic networks, production systems, and frames (Barsalou and Hale, 1993).

Varieties of mathematical reasoning

By its very nature, mathematical reasoning (MR) addresses behaviors that arise from one’s imagination by entertaining possible actions on imaginary (i.e. symbolic) entities (Nemirovsky and Ferrara, 2009). MR entails reasoning with and about abstract symbols and inscriptions that denote these imagined entities and their interrelationships. While MR may seem monolithic, it includes a vast space of behaviors, from very primitive processes involving approximate-number and small-number cardinality that are exhibited by a variety of animal species and human infants, to collaborative discourse and debates over abstract conjectures about universal truths regarding imaginary entities distributed across a range of representational systems and computational resources, that involve multiple disciplinary communities, which may ensue over years and even

centuries. Attending to the varieties of MR is important for evaluating far-reaching claims about its grounded nature. In some cases, the influences of the body and body-based resources such as spatial and temporal metaphor on MR seem to be clear and essential. The uses of concrete manipulatives and gestures are examples. In highly abstract and contemplative forms of MR, such as generating and critiquing a mathematical proof, the role of the body and body-based action seems less certain. Thus, one goal of the framework proposed here is to consider how broadly or narrowly grounding influences the nature of MR.

At a minimum, consideration of the grounded nature of MR entails three relevant dimensions. First, is content: areas such as numbers and operations, arithmetic, algebra, and geometry, which populate the discipline of mathematics (Common Core State Standards Initiative, CCSSI, 2013; Mathematical Association of America, MAA, 2004). Second, is the set of disciplinary practices that characterize doing mathematics, such as precisely executing procedures, finding patterns, using strategies and representations (CCSSI, 2013; Kilpatrick, Swafford, and Findell, 2001; National Council of Teachers of Mathematics, NCTM, 2000). Third, reasoning about specific content and employing particular practices engage psychological processes. Some processes, like attention and working memory, are generally applicable to all MR, while others, like subitizing, procedural fluency, and comprehension, seem specific to particular content areas and practices (see Table 17.1).

The psychological processes that support the MR content and practices draw across many different systems. For example, investigation of the nature and development of *number sense* (taken up in more detail later in this chapter) shows evidence for complementary systems: one is sensitive to approximate magnitudes of quantities, develops very early in humans and other species, and is language- and culture-independent; the other is an exact number system that develops later, serves precise calculations and forms of reasoning, and is mediated by language (Dehaene, 1997).

By arranging the dominant psychological processes that support MR along a logarithmic timescale of human behaviors (Nathan and Alibali, 2010; Newell, 1994) it is possible to cluster MR content and practices with scales of behavior (Table 17.1). Early developing and rapid forms of MR content, such as small approximate number processing, measurement, counting, and basic numerical operations occupy the biological and cognitive bands, supported as they are by rapid perceptual, biological, and simple computational processes such as subitizing, using the approximate number system (ANS), and routinized, knowledge-lean problem solving. Interactive, extended, and distributed forms of MR content, such as complex modeling and proof practices, aggregate in the longer time bands dominated by rational and sociocultural scales.

Conceptually, larger-scale processes supervene on finer-grained ones. In practice, temporal bands demarcate distinct fields of study, sets of research methods, and discourse communities (Nathan and Alibali, 2010). The division between cognitive (seconds) and rational (minutes-hours) bands is particularly notable to this discussion. Behavior in the rational and sociocultural bands is no longer context free – no longer determined primarily by the internal workings of the mental system – as it is at the cognitive and biological bands. Rather, behavior at larger timescales is shaped by constraints provided by context, including specific tasks and goal structures, context-specific knowledge, tool use, cultural norms, and social interactions (Newell, 1994).

Grounding the forms of MR

Lakoff and Núñez (2000) propose an account of the origins of mathematical ideas as grounded in people's sensory and perceptual experiences and body-based actions. Basic mathematical ideas, such as addition-as-collections-of-objects and sets-as-containers, serve as *grounding metaphors* that

Table 17.1 Summary of the mathematical reasoning review

Content	Grounding system			Psychological processes		
	Practices	Body state and actions	Spatial systems	Language and social interactions	Timescale	Level
Number		•	•	•		
Approximate number	Quantification	◦	◦		Milliseconds	Biological
Exact number	Precision			◦	Seconds	Cognitive
Counting	One-to-one correspondence	•	•	•	Seconds	Cognitive
Arithmetic		•	•	•		
Small number	Procedural fluency	◦	◦		Seconds	Cognitive
Large number	Strategies, structure			◦	Minutes-hours	Rational
Rational number	Connections, sense-making			◦	Minutes-hours	Rational
Algebra		•	•	•		
Equations	Strategies, representation	◦	◦	◦	Seconds	Cognitive
Story problems	Problem solving, comprehension	◦		◦	Minutes-hours	Rational
Geometry proof		•	•	•		
Ascertaining	Insight	◦	◦			
Persuading	Argumentation, communication		◦	◦	Milliseconds Days-months	Biological Sociocultural

Note: Solid bullets are for general MR (mathematical-reasoning) content; open bullets are for subtopics.

require little overt instruction and serve as the foundation for more complex ideas. *Conceptual metaphor* is a neural mechanism that enables people to map the conceptual structure of one domain (e.g. arithmetic) to support reasoning about a different domain (e.g. geometry). Abstractions arise when conceptual metaphors from concrete percepts, actions, and experiences are applied, layer upon layer, to support inferences about the behaviors of symbols and other notational inscriptions. Algebraic equations, for example, can be “solved” when algebraic “objects” are “moved” in ways that isolate an unknown quantity while preserving the “balance” of the equation (Nathan, 2008).

Number sense

As noted, infants and many non-human primates and other animals exhibit number sense. They can be trained to respond to the cardinality of one set of stimuli – objects of a certain color and shape, for example – and then respond appropriately when the arrangement of objects, their size, color, and shape are dissimilar, as long as cardinality is maintained. These individuals can also match cardinality across modalities, as when investigators match numbers of objects to tones of varying pitch and duration, or flashes of light. Macaques, for example, can identify the proper number of voices for a given number of faces (Dehaene and Brannon, 2011). Key to these universal feats is that the set of objects and events must remain small, typically five or less.

Humans and other species are sensitive to the magnitudes of numbers, even when those numbers are presented symbolically. In seminal work, Moyer and Landauer (1967) showed that numerical judgment times correlated with number magnitude. When comparing numbers, response times were longer when their relative magnitudes were close together (2 vs. 3 was slower than 2 vs. 9), and with increasing magnitude for the same relative distance (2 vs. 3 was faster than 8 vs. 9). This correlation should not occur if numerals were, strictly speaking, amodal mental symbols. Observations of this pattern of number judgment behavior across a range of stimuli in humans of Western and indigenous cultures, and in other species, has led researchers such as Dehaene and Brannon (2011) to posit the existence of a language- and culture-independent ANS (approximate number system) for representing numerical magnitude (Gallistel and Gelman, 1992) in an analog manner.

Behavioral data also reveal a spatial-numerical association of response code (SNARC) effect, whereby numerical magnitude is analogically represented along a spatial continuum (Dehaene, Bossini, and Giraux, 1993). For example, responses for numerical judgments on smaller magnitudes that do not address magnitude (e.g. parity judgments) are faster for the left hand, and responses for larger ones are faster for the right hand. Brain-imaging studies show that tasks of approximate number arithmetic activate regions typically associated with visuospatial processing (Dehaene, Spelke, Pinel, Stanescu, and Tsivkin, 1999).

For all its power and universality, however, a system for representing and manipulating magnitudes cannot produce the precise, interconnected, and self-referential system that we identify as the discipline of mathematics (Núñez, 2009; Rips, Bloomfield, and Asmuth, 2008). It is necessary to perform *exact mathematics* that mediates accurate counting of large numbers, and precise computational procedures. Behavioral and brain-imaging studies show the exact number system is mediated by language (Dehaene *et al.*, 1999; see Figure 17.1). Patients with language impairments tend to exhibit impaired performance with exact MR, though their reasoning about approximate numbers may be intact. Bilingual (Russian-English) adults trained on either exact or approximate sums in one language or the other showed that access to exact arithmetic information was affected by language format, though this was not the case for approximate number information (Dehaene *et al.*, 1999). Scholars (Dehaene, 1997; Lemer, Dehaene, Spelke,

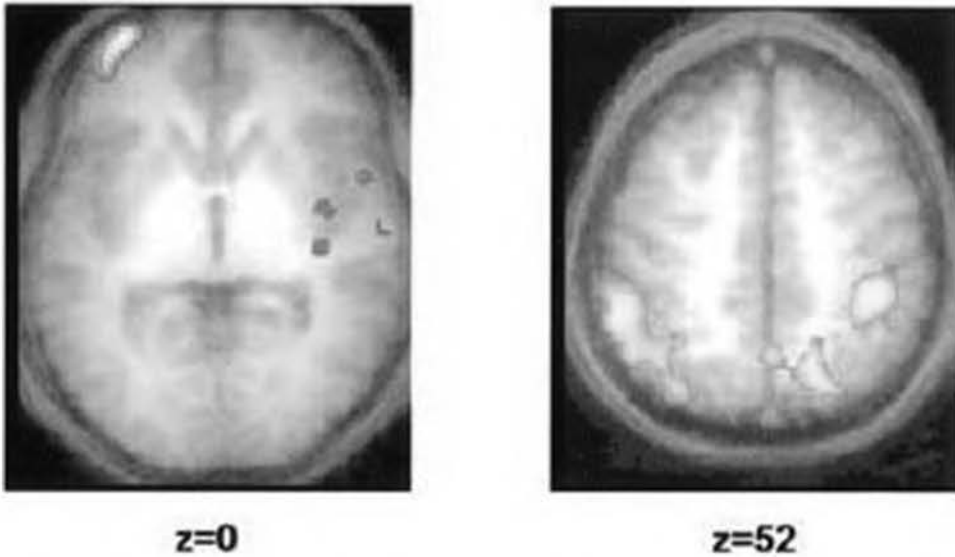


Figure 17.1 Neuroimaging (fMRI) data showing dissociation during exact (highlighted areas, left image; word-association regions) and approximate (highlighted areas, right image; visuospatial regions) calculations (z values indicate the height/depth of the image). (Image taken from Dehaene et al. 1999.)

and Cohen, 2003) suggest the existence of two dissociable systems: an *analog* system for approximate number magnitude; and a *digital* system for exact numerical reasoning and computation. Case and colleagues (e.g. Case *et al.*, 1996) have argued that the integration of number words along with counting activity and magnitude perception are necessary for the conceptual development of number.

Counting

Counting is a skill that develops over time. The agent doing the counting must learn to keep track in order to preserve one-to-one correspondence (Gelman and Gallistel, 1978). For children, hand gestures prove to be important in this developmental process (Butterworth, 1999; Saxe and Kaplan, 1981). Gestures help children to keep track of which items have been counted and which have yet to be counted, and also help coordinate uttering the number word with the appropriate tagging action (Alibali and DiRusso, 1999). More broadly, finger discrimination (e.g. digital gnosis) among five- and six-year-olds is a strong predictor of later math performance (Fayol, Barrouillet, and Marinthe, 1998). Adults apparently retain the symbol-finger association of digital counting behaviors and exhibit muscle activity of the left hand for small numbers (one through four) and of the right hand for larger numbers (six through nine) (Sato, Cattaneo, Rizzolatti, and Gallese, 2007).

Counting is grounded in one's language and cultural practices, as well as one's body-based actions. An intriguing case is the Oksapmin of Papua New Guinea, who use twenty-seven body parts as they transcend in regular order from the thumb of one hand along the fingers, arm, and upper torso and head down to the pinky of the opposing hand (Saxe, 1981). This body-based system is used for counting, numerical comparison, and has been appropriated for monetary calculation as they came in contact with other cultures (Saxe, 1982).

Arithmetic with whole numbers

Finger movement among children and adults performing mental arithmetic suggests that vestiges of counting behaviors are activated, and possibly mediate, computation (Domahs, Krinzinger, and Willmes, 2008). Adults responding verbally showed greater difficulty performing mental addition problems when the sum of the unit digits exceeded 5 (e.g. $3 + 4 = 7$) as compared to items with no such a break (e.g. $5 + 2 = 7$), even though there was no visible use of fingers during the trials (Klein, Moeller, Willmes, Nuerk, and Domahs, 2011). Behavioral differences at the 5 break boundary are notable, since they indicate the role of hands in grounding arithmetic.

Yet language, too, grounds computation. Cross-cultural studies show that exact arithmetic calculations among indigenous cultures proceed well when computational demands remain within the range of the linguistic system, but decline when tasks exceed the range of culturally privileged number words (Gordon, 2004; Pica, Lemer, Izard, and Dehaene, 2004). Members of the Pirahã tribe, who use a “one-two-many” system of counting, show degraded performance with calculations above three. For word problems, performance of both unschooled and schooled children improves when numerical relations map to the appropriate cultural support system (money or time; Baranes, Perry, and Stigler, 1989; Carraher, Carraher, and Schliemann, 1985).

Arithmetic with rational numbers

Investigations of early development of arithmetic that point to the mediating role of the body and language systems are typically designed around additive relations. Multiplicative reasoning is also an essential component of MR, and important for the development of concepts of rational number, probability, and algebra.

Although there is empirical support for early developmental reasoning about ratios and proportions through magnitude estimation (McCrink and Wynn, 2007), multiplicative reasoning is very demanding for children and adults (Bonato, Fabbri, Umiltà, and Zorzi, 2007; Smith, Solomon, and Carey, 2005). Edwards (2009) showed how gestures of pre-service teachers iconically conveyed the conceptual structure of fractions. Representations of multiplicative relationships that are very realistic (e.g. photographs) can hamper proportional reasoning, while more schematized representations (e.g. diagrams) may invoke more analytic forms of reasoning that support more sophisticated MR (Schwartz and Moore, 1998).

Martin and Schwartz (2005) showed that actions using tiles as concrete manipulatives (compared with pictures of the tiles) increased problem-solving performances and later learning of fractions for ten-year-olds. The advantages of performing actions with manipulatives were not due to cognitive offloading, but because students rearranged tiles in service of interpreting the mathematical relations. These findings led Martin (2009, p. 143) to conclude that “actions and interpretations develop each other, and eventually, children develop stable ideas and solve problems using mental strategies.”

Algebra expressions and equations

Algebra equation solving seems to be a quintessential symbol manipulation task (Lewis, 1981), where rules are applied in a goal-directed manner until the equation is solved. Algebra distinguishes itself from arithmetic in that symbols or blanks are included to indicate quantitative relations about unknown and changing quantities (e.g. Carpenter, Franke, and Levi, 2003; Kaput, Carraher, and Blanton, 2008; Riley, Greeno, and Heller, 1983).

Algebraic expressions and equations simultaneously depict process (*subtract 6 from Sarah's age*) and structure (*always six years younger than Sarah*) (Kieran, 1990; Sfard, 1991). Children interpret algebraic expressions as processes before they apprehend their structural qualities, which has ramifications for their abilities to solve equations (Knuth, Alibali, McNeil, Weinberg, and Stephens, 2005; Knuth, Stephens, McNeil, and Alibali, 2006).

Gestures provide important insights into algebraic reasoning. Students' gesture patterns reveal whether they attend to the equal sign of an equation as demarcating the equivalence relation among two expressions (Alibali and Goldin-Meadow, 1993). Manipulating students' gestures can alter their interpretations of the equations (Goldin-Meadow, Cook, and Mitchell, 2009).

Interpretations of algebraic equations are influenced by perceptual relations and implied actions (Kirshner and Awtry, 2004; Landy and Goldstone, 2007). For example, manipulations of a visual background grating moving in a direction compatible or incompatible with the implied movement of symbols for solving an unknown variable affects accuracy (Goldstone, Landy, and Son, 2010). Animations that provide situated referents of symbolic equations improve performance and transfer on equation-solving tasks (Nathan, Kintsch, and Young, 1992). Thus, despite their formal structure, symbolic expressions invoke perceptual and action-based interpretations that are consequential for MR (Nathan, 2012).

Algebra story problems

The conventional wisdom for many years was that story problem solving could be divided into processes of story comprehension and equation solving (see Nathan *et al.*, 1992, for a review). Since equation solving was considered a proper subset of story problem solving as a whole, it stood to reason that story problems were necessarily more difficult than solving equations. Two startling findings turn the conventional wisdom for story problem solving on its head. First, performance is *higher* for algebra story problems than for carefully matched algebra equations (Koedinger and Nathan, 2004). This comes about because students adopt more reliable solution strategies when presented with story problems, and make fewer arithmetic errors. Linguistic forms are helpful in MR, even when they are devoid of the contextual referents of stories that presumably help with abstract reasoning (e.g. Cheng and Holyoak, 1985). Word equations – items which present quantitative relations verbally without context, such as *Starting with some number, if I multiply it by 6 and then add 66, I get 81.90* – exhibit a similar performance advantage over (matched) symbolic equations ($6x + 66 = 81.90$) as do story problems. The locus of effect for word equations is similar as for story problems: they invoke more reliable and meaningful solution methods, and tend to avoid arithmetic slips and computational errors.

Mathematical proof

Despite its typical placement in math curricula, proving is not restricted to the two-column proofs of Euclidean geometry, but is critical to creating and communicating ideas in all branches of mathematics (Knuth, 2002). Harel and Sowder (1998, p. 241) define proving as the primary way “to remove or create doubts about the truth of an observation.” They distinguish between two components: *ascertaining* is an attempt to convince one's self; and *persuading* is an attempt to convince others. Ascertaining often has elements of exploration and insight, while persuading has influences of communication, argumentation, and perspective taking (Nathan, 2013).

Investigators have looked at the role that directed actions and verbal hints play in fostering analytical proofs, specifically, transformational proof schemes, which “involve transformations of

images – perhaps expressed in verbal or written statements – by means of deduction” (Harel and Sowder, 1998, p. 258). Walkington and colleagues (Walkington, Srisurchan, Nathan, Williams, and Alibali 2012; Walkington *et al.*, 2013; Williams *et al.*, 2012) invited undergraduates to touch places on an interactive whiteboard in one of two conditions, either grounding actions, or non-grounding actions. Participants then assessed the truth of a conjecture and verbalized proofs and justifications for their reasoning. For the “triangle task,” the conjecture was

For any triangle, the sum of the lengths of any two sides must be greater than the length of the remaining side.

Participants randomly assigned to the grounding actions condition touched symmetrically positioned spots on the board (scaled to each individual’s arm spans) simultaneously with both hands, and as they did, new spots appeared that were further apart, eventually extending beyond their reach, and in doing so, bringing participants’ chests in contact with the whiteboard (Figure 17.2). In doing these actions, participants essentially made a series of triangles with their arms and the board, which eventually degenerated into parallel lines when the spots exceeded their reach, and the distance from the board to their chest (the altitude of the triangle) was reduced to zero. Those in the non-grounding actions condition performed the same actions, touching the same places with equal frequency, but did not do so with both hands simultaneously, so they never experienced physically embodying the triangles. Though participants reported no awareness of the actions to the conjecture (following Thomas and Lleras, 2007), those in the grounding actions condition were more likely to generate a key mathematical insight for the conjecture than participants in the non-grounding actions condition.

Although actions helped generate the insights related to ascertaining, the action condition by itself did not lead to differences in participants’ abilities to *persuade*, or generate a mathematically correct proof. Participants in the grounding actions condition who received the hint were more likely to generate a mathematically correct proof than those with no hint, even though the hint merely mentioned in general terms that the prior actions could be relevant to the conjecture.

Promoting the insights involved in ascertaining truth for one’s self appears to be influenced by one’s actions, even when the relevance of the actions occur outside of one’s awareness. Persuasion is more socially directed and must adhere to mathematical conventions. Grounding actions are insufficient to promote mathematically correct persuasion without pedagogical directions to connect one’s actions to one’s reasoning. In this way, proof practices reveal some of ways that action and language together ground complex MR.

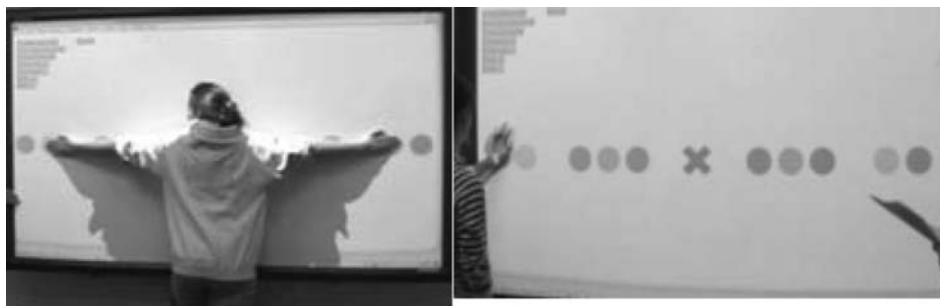


Figure 17.2 Participants perform relevant or irrelevant actions for the triangle task.

Grounded mathematical cognition

This survey of findings from behavioral and biological studies of a broad set of mathematical phenomena observed along various developmental points, including members of post-industrial and indigenous cultural groups substantiates the view that MR is grounded through body states and actions, spatial systems, and language (see Table 17.1). In support of the more constrained views of *embodied cognition*, body-based actions are indicated in tasks involving approximate and exact number sense, small number arithmetic, algebra equations, and the ascertaining phase of proof. Evidence of the importance of spatial systems in these areas of MR are also well established, most notably the presence of the SNARC effect, which shows that the interpretation of numerical symbols are arranged along a number line of increasing values from left to right (for cultures where reading is left to right), and lateralized along the body's left-right axis. Language as a source of grounding is evident across the range of MR tasks as well, even in seemingly non-communicative activities, such as mental arithmetic. Language, of course, cannot be separated from its cultural home (Vygotsky, 1978), and so culture, too, is indicated as a basis for grounded mathematical cognition.

With these findings in place, it is worthwhile to explore several broad themes. First, is to consider the MR literature in terms of Shapiro's (2010) distinction between the types of influence grounding has on cognition. *Conceptualization* addresses how mental events acquire meaning, and how those meanings come to be understood. Conceptualization has its closest parallels with linguistic determinism. Examples from cross-cultural studies of the Pirahã (Gordon, 2004) and the Mundurukú (Pica *et al.*, 2004) show support that the system of grounding influences the type and accuracy of MR. Cross-linguistic studies, such as that with the bilingual Russians (Dehaene *et al.*, 1999), show that conceptualization is as viable in post-industrial cultures as it is in indigenous cultures. *Replacement* holds that the system of grounding can serve in place of some imputed mental representational system. Evidence from ethnographies of the Oksapmin (Saxe, 1981, 1982) demonstrate that locations on the body can serve as the basis of an ordered system capable of supporting MR, which can be appropriated to new systems of quantification, such as learning a monetary system. *Constitution* posits that the processes for grounding cognition, the body-based actions and language-based ideas, may both cause and actually *be* the cognitive behaviors. The constitution hypothesis has its strongest supporters among adherents of situated and distributed cognition. Historically, cognitive science research has neglected those aspects of MR that are considered mathematical *practices*, emphasizing instead mental operations on mathematical content. As the view of MR expands to include the disciplinary behaviors of professionals as they actually do mathematics, support for the constitution hypothesis will inevitably grow, as these practices and the intellectual processes that enable them naturally go hand in hand.

The second issue is to explore how grounded MR can be realized. The Gesture as Simulated Action framework (GSA; Hostetter and Alibali, 2008) hypothesizes that gestures arise during speaking when premotor activation, formed in response to motor or perceptual imagery, is activated beyond a speaker's current gesture inhibition threshold. GSA provides an account of how embodied actions arise as an outgrowth of cognitive activity, and suggests how recurring experiences may reinvolve those actions. The Gesture as Model Enactment (GAME; Nathan and Johnson, 2011) builds on GSA, and proposes that actions coming into the system activate a feed-forward network to generate multiple instances of likely cognitive states, where the most likely state is selected as further evidence is accumulated by tracking movements in relation to the environment and one's goals. GAME also draws on the HMOSAIC (hierarchical modular selection and identification for control) architecture of motor system control (Wolpert, Doya, and Kawato, 2003) and the theory proposed by Glenberg and Gallese (2012) that meaning in

language derives from simulated actions drawn from the same systems that mediate hierarchical, goal-directed (i.e. planned) body movement.

One way to conceptualize these systems that couple motor control with cognitive processes is as *cognition-action transduction*. Transduction is a principle in the physical sciences that accounts for the transformation of one form of energy into another. Familiar transduction devices include electromagnetic motors (which convert electricity to mechanical motion), microphones (acoustic energy into electricity), and LEDs (electricity into light). Transduction devices exhibit an interesting property: they can run in either direction. Applying a force to a motor (reaching in and physically turning a rotor in a blender, for example), will output electrical energy, effectively becoming a generator. Likewise, light passing over an LED generates an electrical current, and effectively operates as a photodetector. The use of grounding action for promoting proof practices (Walkington *et al.*, 2012; Walkington *et al.*, 2013; Williams *et al.*, 2012) shows the potential of this framework for designing new types of interventions to promote conceptual learning in advanced MR through cognition-action transduction.

The third topic is to explore the implications grounded MR has for mathematics education. Identifying activities and curriculum materials that are commensurate with the kind of intellectual processing that mediates MR is a natural recommendation. Methods that support learners in performing the right kinds of actions are seen as positive steps for promoting the development of MR practices and concepts. Examples of effective interventions such as RightStart and Number Worlds (Griffin, Case, and Siegler, 1994; Griffin, 2004) are probably successful because they promote the formation of an integrated system of quantification that organizes one-to-one correspondence with numerals, numerical displays, and number words, all with a mental number line. PDL (physically distributed learning; Martin and Schwartz, 2005) supports MR with fractions by promoting the co-evolution of appropriate actions and interpretations through object rearrangement. Proof practices improve when grounding actions foster students' insights about the conjecture, while hints enabled students to relate these body actions to language-based argumentation, thereby formulating persuasive justifications (Walkington *et al.*, 2012; Walkington *et al.*, 2013; Williams *et al.*, 2012). Growth in support of theories that posit a reciprocal relation between action and cognition (e.g. Andres, Seron, and Olivier, 2007; Martin, 2009; Nathan, 2013) suggest pedagogical alternatives to transmitting propositional information through reading and direct instruction. Yet making overt connections and language-based redescriptions seems necessary to extend tacit insights into a form that will stand up to scrutiny. In this way, grounded MR can enable the individual to be an engaged participant within the community of mathematical thinkers and practitioners; and, like Galileo, foster one's appreciation of the language of the universe.

References

- Alibali, M. W., and DiRusso, A. A. (1999). The function of gesture in learning to count: More than keeping track. *Cognitive Development*, 14(1), 37–56.
- Alibali, M. W., and Goldin-Meadow, S. (1993). Gesture-speech mismatch and mechanisms of learning: What the hands reveal about a child's state of mind. *Cognitive Psychology*, 25, 468–523.
- Andres, M., Seron, X., and Olivier, E. (2007). Contribution of hand motor circuits to counting. *Journal of Cognitive Neuroscience*, 19(4), 563–76.
- Baranes, R., Perry, M., and Stigler, J. W. (1989). Activation of real-world knowledge in the solution of word problems. *Cognition and Instruction*, 6(4), 287–318.
- Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, 59, 617–45.
- Barsalou, L. W., and Hale, C. R. (1993). Components of conceptual representation: From feature lists to recursive frames. In I. Van Mechelen, J. Hampton, R. Michalski, and P. Theuns (Eds.), *Categories and concepts: Theoretical views and inductive data analysis* (pp. 97–144). San Diego, CA: Academic Press.

- Bonato, M., Fabbri, S., Umiltà, C., and Zorzi, M. (2007). The mental representations of numerical fractions: Real or integer? *Journal of Experimental Psychology: Human Perception and Performance*, 33(6), 1410–19.
- Butterworth, B. (1999). *The mathematical brain*. London: Macmillan.
- Carpenter, T. P., Franke, M. L., and Levi, L. (2003). *Thinking mathematically: Integrating arithmetic and algebra in the elementary school*. Portsmouth, NH: Heinemann.
- Carraher, T. N., Carraher, D. W., and Schliemann, A. D. (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology*, 3(1), 21–29.
- Case, R., Okamoto, Y., Griffin, S., McKeough, A., Bleiker, C., Henderson, B., and Keating, D. P. (1996). The role of central conceptual structures in the development of children's thought. *Monographs of the Society for Research in Child Development*, 61(1–2), 1–295.
- CCSSI (Common Core State Standards Initiative) (2013). Mathematics. Retrieved from <http://www.corestandards.org/Math>
- Cheng, P., and Holyoak, K. (1985). Pragmatic reasoning schemas. *Cognitive Psychology*, 17, 391–416.
- Dehaene, S. (1997). *The number sense*. New York: Oxford University Press.
- Dehaene, S., Bossini, S., and Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, 122(3): 371–96.
- Dehaene, S., and Brannon, E. M. (2011). *Space, time and number in the brain: Searching for the foundations of mathematical thought*. London: Academic Press.
- Dehaene, S., Spelke, E., Pinel, P., Stanescu, R., and Tsivkin, S. (1999). Sources of mathematical thinking: Behavioral and brain-imaging evidence. *Science*, 284(5416), 970–74.
- Domahs, F., Krinzinger, H., and Willmes, K. (2008). Mind the gap between both hands: Evidence for internal finger-based number representations in children's mental calculation. *Cortex*, 44(4), 359–67.
- Edwards, L. D. (2009). Gestures and conceptual integration in mathematical talk. *Educational Studies in Mathematics*, 70(2), 127–41.
- Fayol, M., Barrouillet, P., and Marinthe, C. (1998). Predicting arithmetical achievement from neuropsychological performance: A longitudinal study. *Cognition*, 68(2), B63–70.
- Gallistel, C. R., and Gelman, R. (1992). Preverbal and verbal counting and computation. *Cognition*, 44(1), 43–74.
- Gelman, R., and Gallistel, C. R. (1978). *The child's understanding of number*. Cambridge, MA: Harvard University Press.
- Glenberg, A. M., and Gallese, V. (2012). Action-based language: A theory of language acquisition, comprehension, and production. *Cortex*, 48, 905–22.
- Glenberg, A. M., Gutierrez, T., Levin, J. R., Japuntich, S., and Kaschak, M. P. (2004). Activity and imagined activity can enhance young children's reading comprehension. *Journal of Educational Psychology*, 96(3), 424–36.
- Goldin-Meadow, S., Cook, S., and Mitchell, Z. (2009). Gesturing gives children new ideas about math. *Psychological Science*, 20(3), 267–72.
- Goldstone, R. L., Landy, D., and Son, J. Y. (2010). The education of perception. *Topics in Cognitive Science*, 2(2), 265–84.
- Gordon, P. (2004). Numerical cognition without words: Evidence from Amazonia. *Science*, 306, 496–99.
- Griffin, S. (2004). Building number sense with Number Worlds: A mathematics program for young children. *Early Childhood Research Quarterly*, 19(1), 173–80.
- Griffin, S., Case, R., and Siegler, R. (1994). Rightstart: Providing the central conceptual prerequisites for first formal learning of arithmetic to students at risk for school failure. In K. McGilly (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice* (pp. 25–49). Cambridge, MA: MIT Press.
- Harel, G., and Sowder, L. (1998). Students' proof schemes: Results from exploratory studies. *Research in Collegiate Mathematics Education III*, 7, 234–82.
- Hostetter, A. B., and Alibali, M. W. (2008). Visible embodiment: Gestures as simulated action. *Psychonomic Bulletin & Review*, 15(3), 495–514.
- Kaput, J., Carraher, D., and Blanton, M. (2008). *Algebra in the early grades*. Mahwah, NJ: Erlbaum.
- Kieran, C. (1990). Cognitive processes involved in learning school algebra. *Mathematics and cognition: A research synthesis by the International Group for the Psychology of Mathematics Education* (pp. 96–112). Cambridge: Cambridge University Press.
- Kilpatrick, J., Swafford, J., and Findell, B. (2001). *Adding it up: Helping children learn mathematics*. Washington, DC: National Academies Press.
- Kirshner, D., and Awtry, T. (2004). Visual salience of algebraic transformations. *Journal for Research in Mathematics Education*, 35(4), 224–57.

- Klein, E., Moeller, K., Willmes, K., Nuerk, H. C., and Domahs, F. (2011). The influence of implicit hand-based representations on mental arithmetic. *Frontiers in Psychology*, 2(197).
- Knuth, E. J. (2002). Secondary school mathematics teachers' conceptions of proof. *Journal for Research in Mathematics Education*, 33(5), 379–405.
- Knuth, E. J., Alibali, M. W., McNeil, N. M., Weinberg, A., and Stephens, A. C. (2005). Middle school students' understanding of core algebraic concepts: Equivalence and variable. *Zentralblatt für Didaktik der Mathematik*, 37(1), 68–76.
- Knuth, E. J., Stephens, A. C., McNeil, N. M., and Alibali, M. W. (2006). Does understanding the equal sign matter? Evidence from solving equations. *Journal for Research in Mathematics Education*, 37(4), 297–312.
- Koedinger, K. R., and Nathan, M. J. (2004). The real story behind story problems: Effects of representations on quantitative reasoning. *Journal of the Learning Sciences*, 13(2), 129–64.
- Lakoff, G., and Núñez, R. E. (2000). *Where mathematics comes from: How the embodied mind brings mathematics into being*. New York: Basic Books.
- Landy, D., and Goldstone, R. L. (2007). How abstract is symbolic thought? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 33(4), 720–33.
- Lemer, C., Dehaene, S., Spelke, E., and Cohen, L. (2003). Approximate quantities and exact number words: Dissociable systems. *Neuropsychologia*, 41(14), 1942–58.
- Lewis, C. (1981). Skill in algebra. In J. R. Anderson (Ed.), *Cognitive skills and their acquisition* (pp. 85–110). Hove, East Sussex: Psychology Press.
- MAA (Mathematical Association of America) (2004). Core subject taxonomy for mathematical sciences education. MAA website. Retrieved 22 May 2013, from <http://mathdl.maa.org/mathDL/4/?nodeId=337&pa=content&sa=viewDocument> (Based on the Math NSDL Taxonomy Committee report, April 2, 2002, with draft changes proposed for Section 9 by CAUSE, May 16, 2004. Further changes to Section 9 were approved by the Math Gateway Partners Group, April 29, 2005.)
- Martin, T. (2009). A theory of physically distributed learning: How external environments and internal states interact in mathematics learning. *Child Development Perspectives*, 3(3), 140–44.
- Martin, T., and Schwartz, D. L. (2005). Physically distributed learning: Adapting and reinterpreting physical environments in the development of fraction concepts. *Cognitive Science*, 29(4), 587–625.
- McCrink, K., and Wynn, K. (2007). Ratio abstraction by 6-month-old infants. *Psychological Science*, 18(8), 740–45.
- Moyer, R. S., and Landauer, T. K. (1967). Time required for judgments of numerical inequality. *Nature*, 215, 1519–20.
- Nathan, M. J. (2008). An embodied cognition perspective on symbols, gesture and grounding instruction. In M. de Vega, A. M. Glenberg, and A. C. Graesser (Eds.), *Symbols, embodiment and meaning: A debate* (pp. 375–96). Oxford: Oxford University Press.
- (2012). Rethinking formalisms in formal education. *Educational Psychologist*, 47(2), 125–48.
- (2013). Embodied cognition: What it means to know and do mathematics. Keynote presentation to the National Council of Teachers of Mathematics (NCTM) Annual Meeting, Denver, CO.
- Nathan, M. J., and Alibali, M. W. (2010). Learning sciences. *Wiley Interdisciplinary Reviews: Cognitive Science*, 1(3), 329–45.
- Nathan, M. J., and Johnson, C. V. (2011). Gesture as model enactment (GAME): Evidence when learning from text. Paper presented at the American Educational Research Association annual meeting, New Orleans.
- Nathan, M. J., Kintsch, W., and Young, E. (1992). A theory of algebra-word-problem comprehension and its implications for the design of learning environments. *Cognition and Instruction*, 9(4), 329–89.
- NCTM (National Council of Teachers of Mathematics) (2000). *Principles and standards for school mathematics*. Author: Reston, VA.
- Nemirovsky, R., and Ferrara, F. (2009). Mathematical imagination and embodied cognition. *Educational Studies in Mathematics*, 70(2), 159–74.
- Newell, A. (1994). *Unified theories of cognition*. Cambridge, MA: Harvard University Press.
- Núñez, R. (2009). Numbers and arithmetic: Neither hardwired nor out there. *Biological Theory*, 4(1), 68–83.
- Pica, P., Lemer, C., Izard, V., and Dehaene, S. (2004). Exact and approximate arithmetic in an Amazonian indigene group. *Science*, 306, 499–503.
- Riley, M. S., Greeno, J. G., and Heller, J. I. (1983). Development of children's problem-solving ability in arithmetic. In H. P. Ginsburg (Ed.) *The development of mathematical thinking* (pp. 153–96). New York: Academic Press.
- Rips, L. J., Bloomfield, A., and Asmuth, J. (2008). From numerical concepts to concepts of number. *Behavioral and Brain Sciences*, 31, 623–87.

- Sato, M., Cattaneo, L., Rizzolatti, G., and Gallese, V. (2007). Numbers within our hands: Modulation of corticospinal excitability of hand muscles during numerical judgment. *Journal of Cognitive Neuroscience*, 19(4), 684–93.
- Saxe, G. B. (1981). Body parts as numerals: A developmental analysis of numeration among the Oksapmin in Papua New Guinea. *Child Development*, 52(1), 306–16.
- (1982). Developing forms of arithmetical thought among the Oksapmin of Papua New Guinea. *Developmental Psychology*, 18(4), 583–94.
- Saxe, G. B., and Kaplan, R. (1981). Gesture in early counting: A developmental analysis. *Perceptual and Motor Skills*, 53(3), 851–54.
- Schwartz, D. L., and Moore, J. L. (1998). On the role of mathematics in explaining the material world: Mental models for proportional reasoning. *Cognitive Science*, 22, 471–516.
- Sfard, A. (1991). On the dual nature of mathematical conceptions: Reflections on processes and objects as different sides of the same coin. *Educational Studies in Mathematics*, 22, 1–36.
- Shapiro, L. (2010). *Embodied Cognition*. London: Routledge.
- Smith, C. L., Solomon, G. E. A., and Carey, S. (2005). Never getting to zero: Elementary school students' understanding of the infinite divisibility of number and matter. *Cognitive Psychology*, 51, 101–40.
- Thomas, L. E., and Lleras, A. (2007). Moving eyes and moving thought: On the spatial compatibility between eye movements and cognition. *Psychonomic Bulletin & Review*, 14(4), 663–68.
- Vygotsky, L. S. (1978). *Mind in society* (M. Cole, V. John-Steiner, S. Scribner, and E. Souberman, Trans.). Cambridge, MA: Harvard University Press.
- Walkington, C., Nathan, M., Alibali, M., Pier, L., Boncoddio, R., and Williams, C. (2013). Projection as a mechanism for grounding mathematical justification in embodied action. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA.
- Walkington, C., Srisurichan, R., Nathan, M. J., Williams, C. and Alibali, M. W. (2012). Grounding geometry justifications in concrete embodied experience: The link between action and cognition. Paper presented at the American Educational Research Association annual meeting, Vancouver, BC.
- Williams, C., Walkington, C., Boncoddio, R., Srisurichan, R., Pier, E., Nathan, M., and Alibali, M. (2012). Invisible proof: The role of gestures and action in proof. In L. R. Van Zoest, J.-J. Lo, and J. L. Kratky (Eds.), *Proceedings of the 34th Annual Meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education* (pp. 182–89). Kalamazoo, MI: Western Michigan University.
- Wolpert, D. M., Doya, K., and Kawato, M. (2003). A unifying computational framework for motor control and social interaction. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 358(1431), 593–602.

18

EMBODIED INTERACTION, COORDINATION AND REASONING IN COMPUTER GAMEPLAY

Tarja Susi

Embodied cognition has received increasing interest, as seen in research on the many subjects ranging from sensorimotor processes to cultural aspects (e.g. Clark, 2011; Gibbs 2005; Robbins and Aydede, 2009; Shapiro, 2011). There is no one unified conception of the mind, but a general claim is that cognition is grounded in bodily experiences and is distributed across brain, body and environment (e.g. Clark, 1997, 2011). Cognition is a complex phenomenon, and as stated by Gibbs (2005, p. 9), it is “what occurs when the body engages the physical, cultural world and [it] must be studied in terms of the dynamical interactions between people and the environment.” This chapter will discuss embodied interaction, coordination and reasoning in computer gameplay, and the construction of a cooperative two-player computer game to accord with the embodied nature of cognition and action. The computer game discussed here, “The search for the gold reserve,” was developed specifically to be installed as an integral part of an adventure tour in a military fortress. The game was constructed so that players’ whole bodies would be engaged in the gameplay, thereby enhancing the gameplay experience. Playing the game is an “embodied practical activity” (O’Connor and Glenberg, 2003) comprising a mesh of interrelations between the player’s own body, co-players, the players’ cognitions, game devices and the physical context of gameplay, virtual environment and sociocultural aspects. Hence, interaction will be considered in terms of players’ interactions in the real and the virtual environment, in which coordination is essential for solving the tasks encountered in the computer game. As players coordinate their cooperative actions to solve the tasks encountered in the virtual environment, reasoning comes forth as an embodied process with a close intercoupling between players’ perceptions and actions (to include language would reveal further aspects of embodiment, but language is not in focus here¹). The discussion will bring out sensorimotoric, contextual and sociocultural aspects of embodiment,² as embodiment concurrently cuts across the different aspects. Sensorimotoric aspects are mainly discussed in relation to the game’s input/output devices, and the intercoupling between players and the game. Contextual aspects are brought forth by the game environment and the game’s relation to the whole adventure tour, and sociocultural aspects come to the fore through players cooperative problem solving. The different aspects are not discussed separately, but rather as they occur, intertwined, during the gameplay.

Computer game and setting

The computer game was developed to be a part of an adventure tour in an old military fortress located in Karlsborg (south Sweden) (the game development project is described in Wilhelmsson *et al.*, in prep.).³ The fortress itself was built during 1819–1909, and it is now a base for military garrisons, but its unique features have also made it quite a tourist attraction. The adventure tour integrates historical environment, facts, a semi-fictional adventure story and a computer game. Hence, the computer game is set in, and reflects (through its design of graphics), a historically correct environment. The framing story and the different elements of the tour are designed to smudge the borders between the physical environment (the fortress) and the virtual world. The overall scheme of the adventure tour is a search for the national gold reserve that has been stolen and relocated somewhere within the fortress. The framing story is also a battle between good and evil, where visitors are intended to feel they are helping the heroes to find the gold and to reveal the villain. The scene is set by an opening 3D movie⁴ with live actors, which provides the historical context for the tour and introduces the characters involved. The heroes of the adventure are two siblings, a boy and a girl, and the villain is Sgt. Stålhammar. The gold reserve has been transported to the fortress in threat of war, but it has been stolen by a character called “the Rat,” on behalf of Sgt. Stålhammar. The Rat has also drawn a map of the hiding place, and at the end of the movie, the map ends up torn in two pieces, with one part of it in the hands of Sgt. Stålhammar while the girl and the boy get hold of the other part. Then one of the hero characters, either the boy or the girl, appears as a game master (a young male or female) in the movie salon, and tells the visitors that Sgt. Stålhammar will be coming after them as well, since he has seen them. They all need to escape him, to help the hero/game master find the stolen gold. The game master then continues the adventure by bringing the visitors through some of the old parts of the fortress’s vaults. The adventure tour includes, for instance, solving puzzle games, the computer game with renderings of the actual environment, and it finally comes to a dramatic ending in a treasure vault.

The computer game is played in pairs and it is constructed so that players stand side by side on a step platform facing a jDome, a large half sphere on which the game is projected (Figure 18.1). The game is controlled through the step platform⁵ (by movement) with input/output functions, and a hand-held device attached to the step platform by a thin wire (a Gametrak⁶). The setting provides a game environment with eighteen jDomes, which makes it possible for up to thirty-six players to play simultaneously. In contrast to games controlled by, for instance, mouse and keyboard, the game construction allows players to control the game by bodily movements of arms/hands and feet (Figure 18.1).

Some of the requirements that had to be considered when developing the computer game were the target audience (children, 7–13 years of age), the playtime would be 10–15 minutes, there could be no violent contents and the game should not require any training, yet it should be intriguing. To create and withhold interdependency between the overall design of the tour and the game, Caillois’s (1958/2001) taxonomy for games provided a basis, with the basic polarity between *ludus* (rule-governed play) and *paidia* (free play and improvisation) as the point of departure. The participants are part of a rule-governed, arranged adventure, but should also have the feeling of “free play” along the tour. As a narrative vehicle, the overall structure of the adventure tour is scripted and the outcome of events is completely determined before the tour begins, in terms of *what*, *how* and more or less *when*, things will happen. The different rooms included in the adventure tour (with e.g. problem-solving activities) were labeled *agôn* (skill), *alea* (chance), *mimicry* (to mimic) or *illinx* (vertigo) in order to create varied scenarios and experiences for participants. The same categories were also used for the design of the computer



Figure 18.1 The game is controlled through hand-held devices and a step platform, which facilitates a high degree of bodily movement. (Copyright Jan-Olof Fritze.)

game, where settings and characters from the opening 3D movie and the following parts of the adventure tour are integrated in the game environment. The game is designed in an arcade style, and it is quite self-explanatory, which is necessary as players only have one game session and no training. As visitors enter the game location, the game master informs them that the game is played pairwise and that it is controlled through the step platform and the hand-held devices. After the initial introduction, players grasp what to do very fast and once the game is on, their attention is focused on it, and the handling of control devices recedes into the background.

Embodied cooperation and reasoning

The game has three playable rooms, where players need to cooperate to succeed with different tasks. In the first playable room the task is to extinguish a fire with water hoses (Figure 18.2). Each player controls a water hose with the hand-held device, and water pressure is gained by moving on the step platform. Most players become intensely engaged in their movements and adopt different strategies of moving, such as “running” or jumping up and down. Regardless which strategy they chose, there is no obvious logic in how such movements could build up water pressure, but as discussed by Keating and Sunakawa (2011), digital technologies alter what is possible in virtual worlds and players adapt to interactions that “violate some of the constraints of physical spaces” (p. 195). Small movements of the hand-held device could be used to control objects on the screen, but that is not how players use it, or engage in the gameplay.

The pair of players in Figure 18.2, a boy and a woman, are aiming their water hoses towards the flames and their bodily orientation and the way they hold their control devices show they engage their whole bodies, not just performing small movements with their arms/hands. The boy to the left has put his hands together, holding the control device as if holding an object that requires the use of both hands, which would be the case had it been a real hose. As he aims the water hose to the left, he is turning his arms and upper torso to the left. His arms/hands are overly oriented to the left (the angle of hands/arms in relation to the orientation of the hose) as



Figure 18.2 Players cooperating to extinguish the fire. The hand-held device is connected to the step platform by a thin wire (not discernible). The woman standing behind the players is the girl hero character/game master. (Copyright Tommy Holl.)

if trying to convey the water hose even further to the left, although it is already as far to the left on the screen as possible. The woman on the right is slightly leaning to the right with her arms oriented to the right, and she is also holding the control device with both hands. The players coordinate their bodily movements to cooperate in extinguishing the fire by each focusing on different parts of it.

The step platform encourages players to also use their feet to control elements of the game, in this case to gain water pressure. Moving on the step platform provides a quite natural mode of action/interaction as players are standing on it, and running, jumping, etc., are the kind of actions that the object affords (Gibson, 1986). The step platform is also an output device that produces vibrations (of varying force) under the players' feet to create a sensation of vibrating ground. With regard to perception of the environment, Ingold (2011, p. 45) notes that "it is surely through our feet, in contact with the ground (albeit mediated by footwear), that we are most fundamentally and continually 'in touch' with our surroundings." As such, the step platform "grounds" players in the physical environment, but also in virtual space; observations show that most players run or walk on the step platform, when the game characters move on in the game environment. Further grounding in virtual space is developed through facing the large jDome screen, which has quite an immersive effect (further discussed below). The synchronized unfolding of events on the screen, input (movement) and output (vibrations), enhances the players' bodily gameplay experience and possibly the feeling of being "in" the game.

The game has verbal instructions for the fire-extinguishing task (a voice), but as players are solving the task, their real and anticipated bodily movement is shaped by their perception of what happens on the screen, rather than the voice, and the visual experience is a temporarily external pattern of skilful activity (Gibbs, 2005). When aiming the water hose to extinguish the fire, players are not performing abstract reasoning on how to solve the problem, or calculating the best angle for where to aim the water hose (or trying out all possible angles of aiming), and they do not reason about how much movement is required to sustain enough water pressure. Rather, players “call on external resources to perform specific computational tasks” (Clark, 1997, p. 68), and resort to the more primitive task of action-perception (Shapiro, 2011). The task of aiming is performed directly on the screen, intercoupled with perceptions of body movements, water pressure/the water’s reach, and the flames diminishing or growing in different spots. Hence, the graphical elements representing real-world objects, and the hand-held devices, temporarily become external resources for embodied reasoning on aiming and creating water pressure, and for solving the problem of how to extinguish the fire, without conscious, deliberate thinking. As such the graphical elements and the hand-held devices provide cognitive scaffoldings for solving the task, and the perceptual information guides the players’ actions and allows epistemic actions that offload cognitive effort (Clark, 1997; Kirsh, 2009).

In the temporally bounded action of aiming (as well as the other tasks to be solved in the game), the boundary of cognition extends beyond the brain, and the problem-solving task is temporarily intercoupled with the physical and virtual environment. In the words of Wilson and Clark (2009), internal and external resources are fluently tuned and integrated, forming a “transient extended cognitive system” that incorporates technological and sociocultural resources. It is a one-off temporary relationship that “meshes the problem-solving contributions of the human brain and central nervous system with those of the (rest of the) body and various elements of local cognitive scaffolding” (*ibid.*, p. 65).

Reaching into virtual space

In the next playable room, players have to cooperate to catch rats that are running away with gold coins in their mouths, and collect the coins. One player has to grab a rat by its tail and lift it up in the air so the co-player can take the coin from the rat’s mouth. Each player controls a virtual hand that basically performs three actions – grab, lift, let go – which are brought about through the player’s real-space arm/hand movements. A player does not need to make any wide arm movements to activate the virtual hand’s grab, lift and let-go features, the virtual hand only needs to be positioned correctly on the screen, in relation to the rat and the co-player’s virtual hand in the action sequence. However, similar to the previous fire-extinguishing task, in these cooperative tasks players coordinate and synchronize their body movements and actions in physical and virtual space, and the body becomes a resource for the players’ cognitions in a tightly coupled action-perception loop. The task of catching rats is a high paced dynamical one, and players have to act fast to catch any of the rats that appear on the lower edge of the screen, running up the street ahead of the players.

Figures 18.3–6 show a sequence with two players interacting to catch a rat and take the coin from its mouth. The sequence begins as Player 2 (P2, to the right in Figure 18.3) has just grabbed a rat by its tail, and both players are focusing on the actions on the screen, which provides a joint attentional scene (Murray, 2006). P2’s virtual hand is formed in a fist-like grip of the rat’s tail, and he is lifting the rat upwards by lifting his own arm/hand and the control device. Meanwhile, Player 1 (P1) follows P2’s movement by moving his arm/hand and virtual hand upwards to the right.



Figure 18.3 Player 2 (on the right) has just grabbed a rat by its tail and is lifting it up in the air, while Player 1 joins in by moving along his virtual hand. (Copyright Jan-Olof Fritze.)

In Figure 18.4, P2 then holds the rat up in the air so that P1 can move in to take the coin. P2 has raised his hand above shoulder height, and he is holding the control device with three fingers (thumb, index finger and middle finger) while the other two fingers are semi-extended. It is a precision grip that suggests he is literally holding the rat's tail with his own three fingers, rather than manipulating the device and the virtual hand to hold the rat. The gesture crosses the boundaries of real and virtual space, and the player's use of the hand-held device becomes an act of embodying (Hirose, 2002; Wilhelmsson, 2001), in which the device extends his capabilities of perceiving and acting in virtual space, and it ceases to be an object sensed for itself. A typical example of embodying discussed in the literature is a practiced blind person's use of a stick. As the person gets accustomed to using it, it is no longer sensed for itself – instead the stick becomes part of the body, through which the ground is perceived directly (Hirose, 2002). The use of the hand-held device, and by extension the virtual hand, extends the player's action-perception capabilities, although the player acts on visual feedback rather than haptic feedback as when probing with a stick. Considering P2's precise finger grip when holding the rat, the game is, as described by Grodal (2003), a medium for simulation of basic first-person experiences that allows an experiential flow “by linking perceptions, cognitions, and emotions with first-person actions” (p. 132). The simulation of holding the rat then, is an act of virtual embodying that allows reaching into virtual space.

There is a significant difference in P2's gesture and the fist-like grip of his virtual hand on the screen, which suggests the player tunes in on the *action* rather than identifying himself with the virtual hand. Through his gesture and arm movement he embodies the action of holding the rat by its tail in both real and virtual space, which also suggests that the boundary between real and virtual space is changeable. P1 is holding his control device in a different manner than P2 (lower edge, Figure 18.4), but neither is his hand congruent with his virtual hand. P1's virtual hand is wide open with fingers extended while his own hand is formed in a three finger precision grip,



Figure 18.4 Player 2 holds the control device as if holding the rat by the tail. (Copyright Jan-Olof Fritze.)

holding the device with the other two fingers folded along the others. It could be more cumbersome to hold the device with a more open hand, but the hand's configuration suggests he is also tuned in on the action rather than identifying himself with his virtual hand.

In Figure 18.5, P2 has lowered his arm/hand and the virtual hand somewhat, and keeps it rather steady, while P1 is moving his virtual hand closer. At first, P1 makes a few quick moves of his arm/hand up and down, and sideways, and the virtual hand overshoots the target. Both players then adjust and fine tune their arm/hand movements, and virtual hands, for horizontal alignment.

In Figure 18.6, the players have also adjusted their movements and reached vertical alignment of their virtual hands, and so P1 is now in position to grab the coin. The coordination of bodily movement and actions requires not only synchronization in virtual space, but also coordination of bodily movements in physical space. It is a cooperative game with players standing close to each other (with ground space restricted by the step platform), but it requires coordination so that players will not bump into each other or occupy each other's action space. The alignment of bodily movement, then, is directed towards the players themselves, towards each other and with regard to actions in virtual space.

Active participation and immersion

As discussed in the above examples, solving the tasks in the computer game requires cooperation, coordination and synchronization of actions in both real and virtual environment. While playing the game, players pay joint attention to events on the screen and even as they need to make prominent body movements, such as "running," they do not seem to be consciously aware of the



Figure 18.5 The players synchronize and align body movements and virtual elements, for Player 1 to be able to grab the coin that is glimmering in the rat's mouth. (Copyright Jan-Olof Fritze.)



Figure 18.6 The players have synchronized their virtual hands and the rat, and the coin can now be taken from the rat's mouth. (Copyright Jan-Olof Fritze.)

control devices. Rather, their use of the devices seems quite unaware and seamless and, in terms of Pine and Gillmore's participation-connection categorization (in Ermi and Mäyrä, 2005), the gameplay is an "escapist experience," characterized by *active participation* and *immersion*. Ermi and Mäyrä (2005) distinguished three dimensions of immersion in their SCI (sensory, challenge-based and imaginative immersion)-model of gameplay experience, which includes:

- *Sensory immersion*, which relates to the audio-visual surrounds of players. With modern technology – such as "large screens close to the player's face and powerful sounds" (ibid., p. 7) – real-world sensory information is easily overpowered and players become entirely focused on the game.
- *Challenge-based immersion*, which refers to the achievement of balance in challenges and abilities.
- *Imaginative immersion*, which refers to the (possible) use of imagination to empathize with characters or just enjoy the game's fantasy.

The whole gameplay session lasts only about fifteen minutes, yet the game has quite an immersive effect. Considering sensory immersion, players do indeed have a large jDome screen close to their face, there are powerful game sounds (voices and music) and the overall sound level in the game environment is quite loud when all game stations are occupied. However, sensory immersion in this case is not a matter of "audio-visual overpowering" of real-world sensory information, which is instead augmented by haptic feedback through players' feet. Also, the hand-held device provides real-world sensory information in that it is a hand-held object, and its use for controlling the game also strengthens the player's connection with the game's virtual world. Real-world sensory information then, is "built into" the game through the game's input/output devices, which accords with Ingold's (2011, p. 133) view, that "[h]aptic engagement is close range and hands on. It is the engagement of a mindful body at work with materials and with the land, 'sewing itself in' to the textures of the world along the pathways of sensory involvement."

Challenge-based immersion might not seem obvious, considering that the game is quite self-explanatory, only lasts a short time and the tasks to be solved do not require much learning or rehearsing. Yet the game is challenging enough to require certain motor skills (e.g. fine-tuning of hand-eye-control device-virtual element) and cognitive skills (e.g. focused attention and joint problem solving) in order to solve the tasks, which creates a balance between challenges and abilities.

Imaginative immersion might also seem less salient, especially if the game was considered in isolation. However, the game is part and parcel of the narrative that frames the whole adventure tour, and characters are carried over from one part of the tour to another. When the characters – heroes and villains, introduced in the opening movie – (re)appear as animations in the computer game, players recognize them and continue the adventure of pursuing the gold in the heroes' company, while continuing to avoid the villains. Imaginative immersion then, ensues from the game in combination with the overall narrative and structure of the adventure tour.

The different dimensions of immersion contribute to the positive gameplay experience in the present case (as confirmed by our investigations⁷). Ermi and Mäyrä (2005, p. 2) consider gameplay experience to emerge "in a unique interaction process between the game and the player." However, the gameplay experience discussed here emerges not just "between the game and the player," but rather from a unique interaction process that cuts across different aspects of embodiment, as mentioned in the introduction of this chapter. The structure and narrative of the adventure tour and its constituent parts are closely interwoven, and, as seen in Figure 18.2, all elements momentarily converge at the time of the computer gameplay. Characters and

settings from the opening 3D movie and the fortress's milieu are present in the real and the virtual game environment, and the game master who appears both as an animated character in the game, and live (standing behind the players in Figure 18.2), is enacting and carrying out the overall narrative.

The gameplay experience also relates to the players' embodied experience of moving by their own feet through the entire adventure tour. According to Ingold (2011), the most fundamental mode of being in the world is "wayfaring" (as opposed to being "transported"), which he describes as taking place on a meshwork of paths along which the wayfarer moves. Albeit the tour is a micro-scale temporal event compared with a lifetime of wayfaring, the tour is metaphorically and literally a meshwork of paths. The individual game-player's embodied experience of "being in the game" is as much a socially and culturally embodied experience, as it is sensorimotoric; it comprises a rich interplay between the player's body-based cognitions, socially shared activity (e.g. joint problem solving), and cultural experiences, traditions and values (e.g. pre-knowledge of situations, customs; cf. Rogoff, 2003). As visitors move throughout the setting and engage in the gameplay, cooperating in the search for the stolen gold, they also share a social and cultural experience that intertwines mind, body and world.

Summary

The computer gameplay discussed in this chapter is very much an embodied process of co-ordinated interactions in physical and virtual game environment, and reasoning is a process that momentarily extends the boundaries of brain and body, and of real and virtual environment. While common game controls (e.g. mouse and keyboard) pose a challenge in that they delimit the use of bodily resources and modes of interaction, and possibly as a consequence, also players' cognitions, the computer game, "The search for the gold reserve," was constructed to enhance the gameplay experience by allowing players to act in accordance with the embodied nature of cognition and action. At the same time, the computer game, its construction and placement within the fortress's historical setting, and the gameplay experience, show that embodied cognition is an intermingled mesh of sensorimotoric, contextual and sociocultural aspects.

Notes

- 1 Analyses of observations and interviews are still a work in progress, and will also include language to reveal further aspects of embodiment and multimodality.
- 2 A similar conceptualization has been used for situated/embodied cognition and computer gameplay (Susi and Rambusch, 2007; Rambusch, 2011).
- 3 The game was developed in a project that has been running since 2010. The first version (Beta 1) was ready in 2011, and the second version (Beta 2) was ready and installed in the fortress in 2012. The project is funded by Karlsborgs Turism AB.
- 4 The movie is produced by Edithouse Film Works and Big5 Film & TV Productions AB.
- 5 The step platform originated in a research project in which a cave-based firefighter-training game was developed (Backlund, Engström, Hammar, Johannesson, and Lebram, 2007; Lebram, Backlund, Engström, and Johannesson, 2009), but the platform was modified to allow two players to use it simultaneously. The new step platform uses technology similar to what is used in "dance mats" in *Dance Dance Revolution* (Konami, 1998) to register player input.
- 6 The Gametrak is a system of motion-sensing technology, with very accurate position tracking.
- 7 So far, the results from 160 questionnaires, show that visitors are very satisfied with, for instance, the computer game's graphics and that it is played cooperatively, and they easily understand how to play the game.

References

- Backlund, P., Engström, H., Hammar, C., Johannesson, M., and Lebram, M. (2007). SIDH – A game based fire fighter training simulation. In *Information Visualization IV '07: 11th International Conference*. Zurich: IEEE Computer Society.
- Caillois, R. (1958/2001). *Man, play and games*. Urbana-Champaign: Illinois University Press.
- Clark, A. (1997). *Being there: Putting brain, body, and world together again*. Cambridge, MA: MIT Press.
- (2011). *Supersizing the mind: Embodiment, action, and cognitive extension*. Oxford: Oxford University Press.
- Ermi, L., and Mäyrä, F. (2005). Fundamental components of the gameplay experience: Analysing immersion. *Proceedings of DiGRA 2005 Conference: Changing Views – Worlds in Play* (pp. 1–14). Retrieved from <http://www.digra.org/dl>
- Gibbs, R. W., Jr. (2005). *Embodiment and cognitive science*. Cambridge: Cambridge University Press.
- Gibson, J. J. (1986). *The ecological approach to visual perception*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Grodal, T. (2003). Stories for eye, ear, and muscles: Video games, media, and embodied experiences. In M. J. P. Wolf and B. Perron (Eds.), *The video game theory reader* (pp. 129–55). New York: Routledge.
- Hirose, N. (2002). An ecological approach to embodiment and cognition. *Cognitive Systems Research*, 3, 289–99.
- Ingold, T. (2011). *Being alive: Essays on movement, knowledge and description*. London: Routledge.
- Keating, E., and Sunakawa, C. (2011). “A full inspiration tray”: Multimodality across real and virtual spaces. In J. Streeck, C. Goodwin, and C. LeBaron (Eds.), *Embodied interaction: Language and body in the material world* (pp. 194–204). Cambridge: Cambridge University Press.
- Kirsh, D. (2009). Problem solving and situated cognition. In P. Robbins and M. Aydede (Eds.), *The Cambridge handbook of situated cognition* (pp. 264–306). Cambridge: Cambridge University Press.
- Konami (1998). *Dance dance revolution* [Various platforms]. Tokyo: Konami Corporation.
- Lebram, M., Backlund, P., Engström, H., and Johannesson, M. (2009). Design and architecture of Sidh – A cave based firefighter training game in design and use of serious games. In M. Kankaanranta and P. Neittaanmäki (Eds.), *Design and use of serious games* (pp. 19–31). Berlin: Springer.
- Murray, J. H. (2006). Toward a cultural theory of gaming: Digital games and the co-evolution of media, mind, and culture. *Popular Communication*, 4(3), 185–202.
- O'Connor, K., and Glenberg, A. M. (2003). Situated cognition. In *Encyclopedia of cognitive science* (pp. 19–25). London: Nature Publishing Group.
- Rambusch, J. (2011). Mind games extended: Understanding gameplay as situated activity (Doctoral dissertation). Linköping University, Linköping Studies in Science and Technology, Sweden.
- Robbins, P., and Aydede, M. (Eds.) (2009). *The Cambridge handbook of situated cognition*. Cambridge: Cambridge University Press.
- Rogoff, B. (2003). *The cultural nature of human development*. Oxford: Oxford University Press.
- Shapiro, L. (2011). *Embodied cognition*. London: Routledge.
- Susi, T., and Rambusch, J. (2007). Situated play – Just a temporary blip? *Proceedings of DiGRA 2007 Conference: Situated Play* (pp. 730–35). Retrieved from <http://www.digra.org/dl>
- Wilhelmsson, U. (2001). *Enacting the point of being – Computer games, interaction and film theory* (Doctoral dissertation). University of Copenhagen, Denmark.
- Wilhelmsson, U., Toftedahl, M., Susi, T., Torstensson, N., Sjölin, A., and Tuori, P. (in prep.) Reality and fiction integrated – A computer game for enhanced visitor experience.
- Wilson, R. A., and Clark, A. (2009) How to situate cognition: Letting nature take its course. In P. Robbins and M. Aydede (Eds.), *The Cambridge handbook of situated cognition* (pp. 264–306). Cambridge: Cambridge University Press.

PART IV

Applied embodied cognition

Social and moral cognition and emotion

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EMBODIED COGNITION AND THEORY OF MIND

Shannon Spaulding

Introduction

Social cognition is the ability to understand and interact with other agents. Traditionally, philosophers and psychologists have assumed that in order to understand and successfully interact with other people, we must have a *theory of mind*, i.e. a theory about how mental states, such as beliefs, desires, and intentions, inform behavior and how behavior affects mental states. There are two main competing accounts of theory of mind: theory theory (TT) and simulation theory (ST).

TT holds that we explain and predict behavior by employing folk-psychological theories about how mental states inform behavior. With our folk-psychological theories, we infer from a target's behavior what his or her mental states probably are. From these inferences, plus the psychological principles in the theory connecting mental states to behavior, we predict the target's behavior.

ST, in contrast, holds that we explain and predict a target's behavior by using our own minds as a model. We imagine ourselves in the target's situation and figure out what our mental states would be and how we would behave if we were in the target's situation. We retrodictively simulate what the target's mental states could have been to cause the observed behavior, then we take the target's mental states in the form of pretend beliefs and pretend desires as input, run them through our own decision-making mechanism, take the resulting conclusion and attribute it to the target.

TT and ST disagree about how theory of mind works. TT contends that it is an information-rich theoretical process, whereas ST maintains that it is an information-poor simulational process. Though TT and ST proponents disagree about how theory of mind operates, they agree that social cognition requires theory of mind. There is an extensive empirical literature on theory of mind that aims at testing whether our theory of mind is theoretical or simulational in nature, when children develop theory of mind, and whether our theory of mind concepts are innate or learned.

According to embodied cognition, the philosophical and empirical literature on theory of mind is misguided. Embodied cognition rejects the idea that social cognition requires theory of mind. It regards the intramural debate between TT and ST as irrelevant, and it dismisses the empirical studies on theory of mind as ill-conceived and misleading. Embodied cognition provides a novel deflationary account of social cognition that does not depend on theory of mind.

In the next two sections, I shall describe embodied cognition's alternative to theory of mind and discuss three challenges it faces.

Embodied social cognition

Embodied cognition proponents reject the idea that social cognition is based on ascribing mental states to others. On their account, the capacity for more basic, non-mentalistic, interactive embodied practices underlies our ability to understand and interact with others. These interactive embodied practices consist in *primary intersubjectivity* and *secondary intersubjectivity*.

Primary intersubjectivity is the pretheoretical, non-conceptual, embodied understanding of others that underlies and supports the higher-level cognitive skills posited in the theory of mind literature. It is "the innate or early developing capacity to interact with others manifested at the level of perceptual experience – we see or more generally perceive in the other person's bodily movements, facial gestures, eye direction, and so on, what they intend and what they feel" (Gallagher, 2005, p. 204). Primary intersubjectivity is manifested as the capacity for facial imitation and proprioceptive sense of one's body, the capacity to detect and track eye movement, to detect intentional behavior, and to read emotions from actions and expressive movements of others. Primary intersubjectivity consists in informational sensitivity and appropriate responsiveness to specific features of one's environment. It does not, embodied cognition theorists argue, involve representing those features. It simply requires certain practical abilities that have been shaped by selective pressures, e.g. being sensitive to certain bodily cues and facial expressions.

The development of secondary intersubjectivity occurs around age one, and it is marked by a move from one-on-one, immediate intersubjectivity to contexts of shared attention. In addition to tracking eye movement, detecting intentional behavior, and reading emotions, with the development of secondary intersubjectivity the child develops the capacity to communicate with others about objects and events in the environment. The child's interactions with care-takers begin to have reference to the things in their environment. At this stage, the child learns to follow gazes, point, and communicate with others about objects of shared attention. With secondary intersubjectivity, the child's capacity for social understanding is further developed, but according to embodied cognition this understanding is still non-mentalistic (Gallagher, 2005, p. 207).

Embodied cognition holds that these embodied intersubjective practices constitute our primary mode of social cognition (Gallagher, 2005; Hutto, 2008). Daniel Hutto claims, "Our primary worldly engagements are nonrepresentational and do not take the form of intellectual activity" (Hutto, 2008, p. 51). Theory of mind, it is argued, is a late-developing, rarely used, specialized skill. The embodied practices constituted by primary and secondary intersubjectivity are developmentally fundamental. That is, in order to develop the capacity to have beliefs about others' mental states, one must first have a grasp of these basic embodied practices. Moreover, embodied intersubjectivity continues to be our principal mode of social interaction even in adulthood. Even as adults, our ordinary social interactions consist primarily in being sensitive to others' embodied practices.¹

Of course, as adults we do have a capacity for more sophisticated social cognition. This is undeniable. However, according to embodied cognition, this capacity for more sophisticated social cognition does not involve theory of mind. As adults, our everyday social cognition consists only in these embodied practices and our knowledge of the social norms and behavioral scripts distinctive of our social environments. Daniel Hutto's narrative practice hypothesis (NPH) is an embodied-cognition-inspired account of how children develop knowledge of social norms and behavioral practices. It is not the only possible embodied cognition account of sophisticated social cognition, but it is a particularly well-developed account.

NPH holds that the source of our capacity for sophisticated social cognition is direct encounters with folk-psychological narratives, stories that exemplify the forms and norms of social interactions. Stories like “Little Red Riding Hood” and “Goldilocks and the Three Bears” are paradigmatic folk-psychological narratives. The narratives provide exemplars of how agents act according to reasons in order to attain some goal. The child and her caretaker jointly attend to the narrative, and through guided interaction with a caretaker, the child becomes acquainted with forms and norms of acting for reasons. On this view, developing sophisticated social cognition consists in learning how to understand and provide reasons for actions. NPH is meant to be completely independent from theory of mind. Understanding the ways in which agents act for reasons does not consist in, nor does it depend on, attributing beliefs and desires to an agent in order to explain and predict the agent’s behavior. Thus, our sophisticated capacity for social cognition does not consist in or depend on theory of mind (Gallagher and Hutto, 2008).

NPH holds that to be proficient in giving reasons for actions, children must first come to have and attribute propositional attitudes, they must learn how propositional attitudes – e.g. beliefs, desires, and emotions – combine to form reasons for action, and through exposure to folk-psychological narratives they learn the norms of acting for reasons. Only after we master natural language and become proficient in understanding and providing folk-psychological narratives can we learn what is now commonly referred to as *mind-reading*, i.e. explaining and predicting behavior on the basis of attributed mental states. But even then, mind-reading is a rarely used, specialized skill. We mind-read only when our primary modes of social cognition break down, i.e. only when embodied practices are ambiguous and we cannot understand an agent’s behavior in terms of familiar social norms and behavioral scripts.

Because NPH holds that we develop our sophisticated social cognition skills by comprehending folk-psychological narratives, it implies that children could not even be candidate mind-readers until after they master natural language. Thus, there is a chasm between the preverbal social cognition of infants and that of older children and adults. On this view, only those who have mastered language and encountered folk psychological narratives are capable of mind-reading. Non-linguistic and prelinguistic beings’ understanding of others is limited to non-propositional, non-representational, and non-mental understanding (Hutto, 2008, ch. 3). Although NPH is not the only option for embodied cognition, many embodied cognition theorists accept the idea that children are not capable of mind-reading until after they master natural language (Gallagher and Zahavi, 2008; Ratcliffe, 2007).

This idea allegedly is bolstered by results in developmental psychology. For much of the last thirty years, the standard developmental picture of theory of mind has been that at around four years of age, children undergo a fundamental shift in their theory of mind abilities. As Heinz Wimmer and Josef Perner’s experiments first revealed, and other experiments have since replicated, before the age of four children cannot pass standard false-belief tasks (Gopnik and Astington, 1988; Wimmer and Perner, 1983). In one task commonly referred to as the *Sally-Anne task*, children listen to a story as it is enacted with dolls named Sally and Anne. In the scene, Sally hides a toy in one place and then she leaves the scene. Anne moves the toy from the original hiding place to a new hiding place. When children younger than four years old are asked where Sally will look for the toy, they answer incorrectly. They say she will look in the new hiding place. Children four years and older, however, typically answer correctly. They say Sally will look in the original place, and give appropriate explanations for why she will look there. This evidence has been taken to show that there is a significant developmental shift in theory of mind abilities at around four years of age. At age four, children shift from lacking proficiency with the concept of belief to being able to appropriately apply the concept in a range of situations. That is, at age four children master the belief concept. Given that the

concept of belief plays an important role in understanding others' mental states, the standard false-belief task has been taken to be the measuring stick of theory of mind abilities.

Embodied cognition theorists do not regard the standard false-belief task as evidence that theory of mind is *developmentally fundamental* or our *primary* mode of social cognition. They argue that the experimental set-up is not ecologically valid; it does not test our social cognition in ordinary interactions. Nevertheless, they do regard it as evidence for their developmental timeline because it explicitly requires the subject to attribute propositional attitudes to explain and predict the target's behavior. Embodied cognition theorists argue that children must first master language and become proficient in understanding and providing folk-psychological narratives. Only after these developments can children develop the ability to explain and predict behavior on the basis of propositional attitude ascriptions. Thus, despite the mistaken assumptions about the importance of the cognitive skills tested in the standard false-belief task, the fact that children first pass this task around the same age that they master the forms and norms of folk-psychological narratives is evidence for the developmental timeline suggested by embodied cognition.

Embodied cognition theorists take the results of the standard false-belief task as evidence for their claim that children are not even capable of mind-reading until fairly late in development, which suggests that theory of mind is not developmentally fundamental. What is developmentally fundamental is embodied intersubjectivity. Embodied intersubjectivity, along with knowledge of social norms and behavioral scripts, make up our ordinary social cognitive interactions even as adults.

Challenges for embodied cognition

In this section, I identify three challenges for embodied accounts of social cognition.² The first problem is that they rely on outdated empirical data. Second, they leave an unbridged gap between the kind of social cognitive capacities of preverbal children and the social cognitive capacities of older children and adults. Third, embodied theories of social cognition focus exclusively on "online" cognitive processes, thereby neglecting the legitimate and important role of "offline" cognitive processes. None of these challenges is insurmountable, but I do take them to be serious shortcomings that embodied cognition must address.

Outdated developmental timeline

As I pointed out above, embodied social cognition acquires evidence for its developmental timeline from the results of the standard false-belief task. However, the standard false-belief task is no longer regarded as a good test for theory of mind abilities. Paul Bloom and Tim German persuasively argue that passing the standard false-belief task is neither necessary nor sufficient for theory of mind. The standard false-belief task tests for a variety of general cognitive skills that are not specifically theory of mind skills, and explicit reasoning about false beliefs is not necessary for theory of mind (Bloom and German, 2000).

Kristine Onishi and Renée Baillargeon (2005) object to the standard false-belief tasks, arguing that these tasks are computationally and linguistically too taxing for children younger than four years old. The standard false-belief task requires children to remember the details of the story, who saw what and when, to interpret adults' questions, and give appropriate responses to these questions. Many of these task demands are unrelated to theory of mind per se. Rather, the demands of the standard false-belief task reveal performance of executive functions, e.g. memory

and response inhibition. In lieu of the standard measuring stick, Onishi and Baillargeon opt for a simplified non-linguistic false-belief task to measure theory of mind abilities of younger children.

In their novel non-linguistic false-belief task, fifteen-month-old infants watch an actor put a toy watermelon slice in one of two adjacent boxes, a green box or yellow box. Next, the toy is moved. In half the trials the toy is moved halfway to the other box and then back to the original box, and in the other half of the trials the toy is moved to the other box. For both of these conditions the actor either does or does not see the movement of the toy. (In one variation she looks through an opening in the tops of the boxes, and in another variation she does not.) Using the violation-of-expectation method, Onishi and Baillargeon found that fifteen-month-old infants looked longer in two cases: first, when the actor does not see that the toy's location has changed, but searches in the correct box anyway, and second, when the actor does see the toy being relocated but the actor reaches in the incorrect box.

Onishi and Baillargeon interpret these results as showing that the fifteen-month-old infants expect the actor to search for the toy on the basis of her belief about the toy's location. When the actor does not search for the toy on the basis of her belief, the infants' expectations are violated and they thus looked longer at those events. Onishi and Baillargeon take this to be good evidence for the conclusion that fifteen-month-old infants already have mind-reading abilities and that the ability to mind-read, in at least a rudimentary form, is innate.

Onishi and Baillargeon were the first to use non-linguistic methods for testing false-belief understanding. Since the publication of their article, numerous studies employing a variety of non-verbal testing methods – anticipatory looking, violation of expectation, and active helping – have found evidence that preverbal infants are sensitive to others' intentions, perceptions, perspectives regarding objects, intentions in pretend scenarios, etc. (Gergely, Bekkering, and Kirly, 2002; Luo and Baillargeon, 2007; Onishi, Baillargeon, and Leslie, 2007; Song and Baillargeon, 2007). For example, Baillargeon and colleagues found that five-month-old infants expect agents to act according to their preferences, and they looked longer when agents act contrary to their exhibited preferences.

[A]fter watching familiarization events in which an agent repeatedly grasps object-A, infants look longer at test events if the agent now grasps object-B, but only if object-B is both present and visible to the agent during the familiarization events, so that infants have evidence that the agent prefers object-A over object-B. These different looking-patterns indicate that infants do not merely form associations but consider (at the very least) the motivational and reality-incongruent informational states that underlie agents' actions.

(Baillargeon, Scott, and He, 2010, p. 115)

This study, and dozens others like it, purport to show that children are sensitive to others' mental states long before they can pass the standard false-belief task. The standard false-belief task, it is argued, tests for children's ability to express linguistically what they are capable of understanding long before age four.

Given that embodied cognition theorists are committed to the idea that children are not capable of mind-reading until after they master natural language and become proficient with folk-psychological narratives, they must reject these empirical findings. They must argue that we can explain the infants' behaviors without attributing to them precocious mind-reading abilities. Their task is to reinterpret the results in terms of non-mentalistic behavior-based explanations, e.g. infants learn the behavioral rule that "agents look for an object where they last saw it."

Currently, there is a vigorous debate about how to understand the results of these non-linguistic mind-reading tasks. Some argue that these studies show that infants understand false beliefs and perhaps already possess the belief concept. According to this interpretation, the reason children fail the standard false-belief task until age four is that up until age four the task is too demanding on younger children's executive system, e.g. short-term memory and response inhibition (Baillargeon *et al.*, 2010; Leslie, Friedman, and German, 2004; Onishi and Baillargeon, 2005). Others argue that these studies show that infants must be very clever behavior readers because it is not possible for infants to understand false beliefs or possess the belief concept. On this interpretation, children four years and younger fail the standard false-belief task because up until age four they do not fully grasp the belief concept (Perner and Ruffman, 2005).

Embodied cognition is committed to the latter interpretation of these studies. Thus, they must argue for a reinterpretation of the results of the studies in terms of behavioral rules and associations. Unfortunately, however, embodied cognition theorists do not provide such a reinterpretation. They mostly ignore these findings because they regard them as tainted by the presupposition that mind-reading is a fundamental part of our ordinary social cognitive interactions. This is unfortunate for two reasons.

First, there is a growing body of evidence suggesting that infants really are capable of more than just non-mentalistic behavior-reading. This body of evidence is growing in terms of the diversity of experimental paradigms employed and the number of studies finding that infants are sensitive to others' mental states. As these findings become more robust, explaining away these results in terms of ad hoc behavioral associations and rules becomes less appealing. These experimental results make the developmental timeline of the standard false-belief task look much less plausible, which is bad news for embodied cognition's account of social cognition.

Second, although embodied cognition theorists may be right that these studies presuppose that mind-reading is a fundamental part of our ordinary social interactions, this does not mean they should simply ignore these findings. Embodied cognition theorists ought to explain what they think really is happening in these studies and how we should understand these results. Otherwise, embodied cognition is open to the obvious objection that it is in conflict with much of the contemporary data from developmental psychology. Thus, the first challenge that embodied cognition faces is to justify its reliance on a developmental timeline that appears to have been empirically falsified.

Cognitive gap

Suppose that embodied cognition's developmental timeline is correct, and we can explain adequately all of the results of the new wave, non-linguistic mind-reading tests in terms of non-mentalistic embodied cues and behavioral rules and associations. If this is the case, then infants and young children do not, indeed cannot, explain and predict behavior on the basis of mental state attributions. In other words, preverbal children cannot mind-read. Older children and adults, however, can mind-read. Thus, there is a cognitive gap between the social cognitive capacities of preverbal children and the social cognitive capacities of older children and adults. Even if mind-reading is rare for older children and adults, embodied cognition needs an account of *how* we develop the capacity for mind-reading from purely non-mentalistic embodied cues (Wilby, 2012).

A comprehensive account of social cognition must describe our social cognitive capacities as infants and young children, our social cognitive capacities as older children and adults, and how we develop the latter from the former. Embodied cognition theorists focus on denying that

infants and young children can mind-read and denying that mind-reading is prevalent even in adults, the result of which is that they neglect to explain how we develop this capacity for mind-reading. This gap is problematic because it is not obvious how a capacity for mind-reading could develop from purely non-mentalistic embodied practices. Embodied cognition theorists often cite the mastery of natural language as the basis for developing the capacity for mind-reading. But this is not an explanation; it is a placeholder for an explanation. To have a comprehensive account, embodied cognition must explain how the mastery of natural language enables children to develop the capacity for mind-reading.³

NPH may offer the most promising account of how children develop the capacity for mind-reading. Once children master natural language and become proficient with the forms and norms of folk-psychological narratives, they can begin to understand how beliefs and desires interact to form reasons for actions. Once they understand reasons for actions, they learn to explain and predict behavior in terms of these reasons for actions. The problem with this account is that it seems to have the story backwards (Spaulding, 2011; Thompson, 2012). On the face of it, one could not understand folk-psychological narratives without already understanding how mental states cause behavior. Understanding the *folk-psychological* aspect of folk-psychological narratives seems to presuppose a capacity for mind-reading. To face this challenge, embodied cognition proponents must show that mastering folk-psychological narratives does not presuppose a capacity for mind-reading.

Neglect of offline processes

The final challenge for embodied cognition concerns the comprehensiveness of the account. Embodied cognition focuses exclusively on the role of *online* processes in social cognition (de Bruin and Kästner, 2012). Online processes are cognitive processes that involve responding directly to, rather than representing, features of the environment. Embodied cognition's notion of embodied intersubjectivity illustrates this well. Embodied intersubjectivity consists in primary and secondary intersubjectivity: facial imitation and proprioceptive sense of one's body, the capacity to detect and track eye movement, to detect intentional behavior, and to read emotions from actions and expressive movements of others, and joint attention. Embodied cognition regards these as online, non-representational cognitive processes, and aims to explain our social interactions in terms of these online processes.

Online processes are an important element of social cognition, of course. Embodied cognition is surely right that these online processes are developmentally fundamental. An account of social cognition would be inadequate if it failed to include a role for online processes such as facial imitation, tracking eye movement, and detecting intentional behavior. Embodied cognition theorists allege that theory of mind accounts are guilty of neglecting the role of online processes and focusing exclusively on *offline* processes.

In contrast to online processes, *offline* processes involve internal representations, which are not bound to the current features of the agent's body or her environment, e.g. propositional attitude ascriptions. Theory of mind accounts assume that the mind is an intracranial information-processing system. On this view, cognition is a computational process of manipulating symbolic representations. Theory of mind accounts focus on our ability to explain and predict others' behaviors in terms of mental state attributions. They explain these social cognitive capacities by adverting to computational processes, modular mechanisms, internal representations, and so on. Given the emphasis on these offline computational processes, these accounts tend to neglect the role of *online* processes in social cognition. Embodied cognition rejects the idea assumed in the

philosophical and empirical literature on theory of mind that social cognition primarily involves offline processes. Embodied cognition theorists regard this assumption as false and aim to show that social cognition is best explicable in terms of online processes.

Of course, we employ both online and offline cognitive processes in our social interactions. Social cognition requires both responding directly to features of the environment and manipulating information that is absent from the environment and so has to be internally represented. Embodied cognition theorists do not deny this. They do not regard offline cognitive processes as impossible. They simply regard them as relatively unimportant. And this is a mistake. In many cases, it is beneficial to withdraw from the immediate surroundings so as not to automatically act upon particular affordances. Think of the enormous cognitive benefit the capacity to engage in counterfactual reasoning affords. Instead of simply engaging directly with the environment, the agent may consider other ways to respond to the environment, consider hypothetical action plans, evaluate various means of achieving one's goals, etc.

Moreover, the separation of online and offline processes is artificial. An agent's online and offline processes interact to yield cognitive flexibility and autonomy from environmental stimulation such that the agent becomes less dependent upon, and gains new ways of relating to, her environment and other agents in her environment. For example, when we perceive someone blushing, we may take into consideration what immediately happened that could have caused the blush, this person's recent history and personality, and social knowledge about what causes people to blush. Inferring that the person is blushing because she is angry gives rise to different interaction than inferring that she is embarrassed. And inferring that she is embarrassed about something *she* said yields a different sort of online interaction than inferring that she is embarrassed by something *you* said. When we perceive the blush, we automatically take into consideration background information, and the background information influences how we perceive the situation. In order to be a comprehensive account of social cognition, embodied cognition must recognize the legitimate and important role such offline processes play in social cognition.⁴

Conclusion

Embodied cognition's deflationary account is a welcome challenge to the theory of mind orthodoxy. It prompts traditional theory of mind accounts to justify the assumption that we must and often do attribute propositional attitudes to others in order to understand and interact with them. It spurs theory of mind advocates to consider the neglected role of embodied practices and online processes. Consideration of this deflationary account of social cognition brings to light assumptions of the theory of mind literature that need reconsideration. Embodied cognition encourages us to scrutinize the presuppositions and conclusions of the empirical literature on social cognition.

Embodied cognition provides a different paradigm for studying social cognition. To provide a comprehensive, adequate account of social cognition, embodied cognition needs to answer the challenges described above. This requires considering the new wave false-belief tasks and other non-linguistic theory of mind tasks. Embodied cognition proponents need to respond to the objection that their account relies on an empirically disconfirmed developmental timeline and provide an alternative explanation of these empirical results. They must explain how exactly sophisticated social cognition develops from non-mentalistic embodied practices. And they must make room in their account for the legitimate and important role of offline processes in social cognition.

It is an open question whether embodied cognition or theory of mind offers a more compelling account of social cognition. My own view is that embodied cognition has some distance to go before we can declare it the superior account. It is clear, however, that the debate about social cognition has benefited greatly from this clash of paradigms. Embodied cognition highlights genuine shortcomings and questionable assumptions of theory of mind and provides a radically different alternative account of social cognition. The introduction of this radically different account has revived stagnant debates and spurred re-evaluation of old theory of mind dogmas. This clashing of paradigms is the best way forward for the debate about social cognition.

Notes

- 1 For a critical assessment of these ideas, see Spaulding, 2010.
- 2 See Spaulding, 2012, for a guide to discussions about embodied social cognition.
- 3 See Wilby, 2012, for an evaluation of various attempts to close this cognitive gap.
- 4 See de Bruin and Kästner, 2012, for an extended defense of this argument and a positive account of how online and offline social cognition processes dynamically interact.

References

- Baillargeon, R., Scott, R., and He, Z. (2010). False-belief understanding in infants. *Trends in Cognitive Sciences*, 14(3), 110–18.
- Bloom, P., and German, T. P. (2000). Two reasons to abandon the false belief task as a test of theory of mind. *Cognition*, 77(1), 25–31.
- de Bruin, L. C., and Kästner, L. (2012). Dynamic embodied cognition. *Phenomenology and the Cognitive Sciences*, 11(4), 541–63.
- Gallagher, S. (2005). *How the body shapes the mind*. New York: Oxford University Press.
- Gallagher, S., and Hutto, D. D. (2008). Understanding others through primary interaction and narrative practice. In J. Zlatev, T. P. Racine, C. Sinha, and E. Itkonen (Eds.), *The shared mind: Perspectives on intersubjectivity*. Amsterdam: John Benjamins.
- Gallagher, S., and Zahavi, D. (2008). *The phenomenological mind: An introduction to philosophy of mind and cognitive science*. New York: Routledge.
- Gergely, G., Bekkering, H., and Kirly, I. (2002). Developmental psychology: Rational imitation in preverbal infants. *Nature*, 415(6873), 755–56.
- Gopnik, A., and Astington, J. W. (1988). Children's understanding of representational change and its relation to the understanding of false belief and the appearance-reality distinction. *Child Development*, 59(1), 26–37.
- Hutto, D. D. (2008). *Folk psychological narratives: The sociocultural basis of understanding reasons*. Cambridge, MA: MIT Press.
- Leslie, A. M., Friedman, O., and German, T. P. (2004). Core mechanisms in "theory of mind." *Trends in Cognitive Sciences*, 8(12), 528–33.
- Luo, Y., and Baillargeon, R. (2007). Do 12.5-month-old infants consider what objects others can see when interpreting their actions? *Cognition*, 105(3), 489–512.
- Onishi, K. H., and Baillargeon, R. (2005). Do 15-month-old infants understand false beliefs? *Science*, 308(5719), 255–58.
- Onishi, K. H., Baillargeon, R., and Leslie, A. M. (2007). 15-month-old infants detect violations in pretend scenarios. *Acta Psychologica*, 124(1), 106–28.
- Perner, J., and Ruffman, T. (2005). Infants' insight into the mind: How deep? *Science*, 308(5719), 214.
- Ratcliffe, M. (2007). *Rethinking commonsense psychology*. New York: Palgrave Macmillan.
- Song, H., and Baillargeon, R. (2007). Can 9.5-month-old infants attribute to an agent a disposition to perform a particular action on objects? *Acta Psychologica*, 124(1), 79–105.
- Spaulding, S. (2010). Embodied cognition and mindreading. *Mind & Language*, 25(1), 119–40.
- (2011). A critique of embodied simulation. *Review of Philosophy and Psychology*, 2(3), 579–99.
- (2012). Introduction to debates on embodied social cognition. *Phenomenology and the Cognitive Sciences*, 11(4), 431–48.

- Thompson, J. (2012). Implicit mindreading and embodied cognition. *Phenomenology and the Cognitive Sciences*, 11(4), 449–66.
- Wilby, M. (2012). Embodying the false-belief tasks. *Phenomenology and the Cognitive Sciences*, 11(4), 519–40.
- Wimmer, H., and Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition*, 13(1), 103–28.

THE EMBODIMENT OF CULTURE

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What is the nature of culture? Is it a form of human values that floats above individual experience? Or, does culture arise from the mundane interactions of individuals with their physical and social environments? We provide answers to these questions in the following four sections of this chapter. In the first, we describe problems with standard conceptions of culture, including how it is learned and transmitted and how culture interfaces with psychological experience. In the second, we develop an approach based on ideas of embodied cognition: at the level of the individual and the small group (e.g. family), culture is the tuning of sensorimotor systems for situated action. In the third and fourth sections, we sketch the results from two empirical investigations that demonstrate the promise of this approach. One of the investigations documents how culture can influence distance perception by taking into account expected effort of interaction (e.g. Proffitt, 2006) with in-group and out-group members. The second demonstrates how close physical interaction of the sort hypothesized to lead to sensorimotor tuning can literally change the body schema so that dyads become closely attuned to one another; that is, they form an in-group.

The problem: a dualistic conception of culture

Pinning down a commonly accepted psychological characterization of culture is difficult (cf. Atran, Medin, and Ross, 2005; Kitayama, 2002; Kroeber and Kluckhohn, 1963; Tripathi, 2001). Nonetheless, there are two common working assumptions. The first is that culture is a package of propositional constructs like values, beliefs, and world views (Markus and Kitayama, 1991; Oyserman, Coon, and Kemmelmeier, 2002; Triandis, 1995). These rule-like structures specify the normative or prescriptive social code prevailing in the local group. The second is that this cultural grammar provides frames for making sense of incoming information, and simultaneously functions as the motivational force that biases behavior in predictable directions (Hong and Chiu, 2001). Note that these working assumptions create a duality: culture is both a set of abstract norms and a set of sensorimotor behaviors.

This duality is found amongst researchers who argue that culture proper should be exclusively identified with the abstract norms (Oyserman *et al.*, 2002), and also amongst advocates of a broader conception of culture that encompasses both ideations and behaviors (Kitayama, 2002;

Markus and Kitayama, 2010). The camps differ only as to whether genuine culture should be confined to one of the elements of this duality.

The duality raises questions such as, “What if stated values and observable behavior do not coincide?” and “Where should the label of ‘genuine culture’ be attached?” As an example, Cohen and colleagues (Cohen, Nisbett, Bowdle, and Schwarz, 1996) arranged for male participants from the southern and northern US to be bumped and then called “assholes.” The researchers then collected biomarkers of stress and aggression and placed the participants once again in a potentially insulting situation. Relative to the northern participants, southerners showed an increase in cortisol (indexing stress) and testosterone (indexing potential aggression) levels, as well as a stronger behavioral face-off tendency during the second episode of potential insult. Thus, Cohen *et al.* produced strong behavioral and physiological evidence to claim that the South is dominated by a “culture of honor” that stresses masculine toughness and aggressive defense of reputation. Several years later, however, D’Andrade (2000) used verbal questionnaires to excavate the abstract normative value system that allegedly underlies those bodily manifestations of honor. But D’Andrade found no difference between southerners and northerners in value systems. Does honor exist apart from its bodily “manifestations?” Is the “value system” of honor psychologically real?

The discrepancy between the proposed genuine ideological foundations of culture and its behavioral manifestations is especially conspicuous in cognitive sociology. Swidler’s (2001) informants endorsed the ideological belief that love is the basic motivation for marriage. But in contrast to this endorsed value, they did not actually bring their marriages to an end despite admitting that their marriages were no longer sentimentally fulfilling. Similarly, Vaisey (2008) interviewed teenage informants after they chose (on a survey) either to “do what makes me happy” or “do what God or scripture says.” During the interview, both groups made similar decisions about acting in practical situations that implicitly required moral decisions. When asked to justify their behavioral choices, both converged on “gut instinct” and when pressed, they offered incoherent justifications. This finding is similar to those of Haidt and Hersh (2001) who report that participants rejected culturally degenerate acts (e.g. recreational drug use), but resorted to vague rationalizations for doing so.

The dual working assumptions also seem to produce a bias when interpreting observed effects of culture in regard to cause and effect. If in one and the same cultural population, a unique social characteristic is reliably established (e.g. how the individual relates to the in-group and out-groups) and a distinctive sensorimotor tendency is equally reliably marked as prevalent (e.g. the scope of visual attention, categorization biases, memory of inanimate scenes, or learning styles), only the former is characterized as defining for the cultural profile of the group, whereas the latter is typically conceived as the effect of culture on cognition (e.g. Nisbett and Miyamoto, 2005; Norenzayan, Smith, Kim, and Nisbett, 2002; Varnum, Grossman, Kitayama, and Nisbett, 2010). That is, the abstract norms are conceived as constitutive of the psychological fabric of culture and the sensorimotor behaviors merely secondary or consequent.

Markus and Kitayama’s (1991) seminal conception of the “self” is an exemplar of this bias in interpretation. The main postulate is that the “self” is an emergent, abstract set of norms reflecting the individual-group relationship dominant in the local setting. In individualistic societies (e.g. North America), the value system stresses freedom of choice and achievement, while collectivistic cultures (e.g. East Asians) stress group-connectedness and social commitment. Individuals in the former setting typically develop “independent” self-construals with social orientations that center around self-direction, autonomy, and freedom of expression. In the collectivistic settings, “interdependent” self-construals are anchored in harmony and social commitment. Critically, Markus and Kitayama stressed that “... these divergent views of the

independent and interdependent selves can have a systematic influence on various aspects of cognition ... ” (1991, p. 224), a view that is rephrased in their recent review of the theory as “Independence and interdependence have significant consequences for cognition” (Markus and Kitayama, 2010, p. 425).

An alternative: the sensorimotor account of culture and behavior

In our alternative, there is no self-contained, multilayered psychological structure that could be labeled “culture.” We do not claim that culture does not exist, nor do we assert that culture is not a valuable construct at the sociological level of analysis. Instead the claim is that culture is not a psychological structure that exists apart from more mundane learning and behavior. Thus, our account aims to substitute for the dualistic value–behavior conception of culture a unifying postulate: the psychological underpinning of culture consists of an individual’s sensorimotor tuning arising from and guiding social interactions.

An important point of departure for our account is a particular understanding of human knowledge. The embodied approach assumes that knowledge resides in the multimodal manner in which the agent interacts with the environment. On this account, the body is not a mere input and output device controlled by a cognitive machine. Instead, both the anatomical and physiological sensorimotor characteristics of the body define the knowledge profile of the agent.

Convincing examples come from developmental psychology. For example, Dahl *et al.* (2013) demonstrate how the maturation that enables crawling sets the stage for a new type of sensorimotor knowledge that then becomes the basis for understanding stability in the world and wariness of heights. When an infant is being carried, there is no consistent correlation between the infant’s proprioception and visual stimulation. However, once the infant begins to crawl, she keeps her head steadily pointed toward the goal. In this way, the infant can experience the consistent and strong correlations between commands to the muscles, proprioceptive feedback, and importantly, optic flow. This correlation then becomes the basis for a stable world. That is, a particular type of movement produces a particular flow of optical information, and it is that correlation that indicates that the world is stable and it is the infant that is moving within it. When that correlation is disrupted, it is a signal that the world is changing and that caution is needed. For the infant in the laboratory, that disruption is caused by placing the infant near a visual cliff, which causes the infant distress, but only after it has learned to crawl and tune itself to the correlation of proprioception and optic flow. Adults experience this sort of distress when in a stopped car and another car in the periphery begins to move. The sensation is that the world is changing and that one’s own car is moving, and it produces a fearful stomping on the brakes.

As another example, Sommerville, Woodward, and Needham (2005) show that three-month-old infants can attend to adult goals, such as grabbing an object, but only after the infant develops some skill in grabbing and holding objects herself. Similarly, with older children, categorization of objects depends on how they have interacted with them (Smith, 2005). These examples demonstrate how knowledge, both particular and abstract (e.g. knowledge defining a stable world, knowledge about goals, and knowledge about categories) arises from sensorimotor interaction with the world.

We propose, similarly, that culture enters the scene not as a self-contained layer on top of behavior, but as the sum of sensorimotor knowledge brought about by a bodily agent interacting in a social and physical context. As such, culture diffuses the web of sensorimotor knowledge, and can only be arbitrarily circumscribed from other knowledge.

In the next few paragraphs, and in the research we present later, we apply this sensorimotor account to the development of interdependent and independent selves. We do not see this as the only application of the account, but as an example of how it applies to questions regarding culture.

On our view, interdependent and independent selves are constituted primarily by two pervasive types of sensorimotor interactions that are acquired and maintained through immersion in environments with different patterns of interpersonal interactions. The interdependent self develops when there are close interactions with the family and in-group members. These interactions “tune” the sensorimotor system to promote efficient interactions within this group. By tuning, we mean a process of neuroplasticity, or learning. For example, on learning a new behavior (e.g. how to crawl, how to walk, or how to talk), the mirror neuron system (Gallese, Keysers, and Rizzolatti, 2004; Rizzolatti and Craighero, 2004) tunes itself so that these skills are used in recognizing the homologous actions taken by others. After tuning of this sort, recognizing those actions is faster and more efficient than before tuning.

Furthermore, we propose that after sufficient sensorimotor tuning, the familiarity and fluency of tuned actions confer on these routines a value-like normative status; they become the “natural” way of engaging the world. Thus, strong sensorimotor tuning creates an in-group: the people with whom interactions are literally easy, efficient, and thereby enjoyable. In contrast, when people look, dress, smell, or talk differently, it is, we propose, literally more difficult to interact with them. As an example, consider conversing with an unskilled speaker of English; it can be difficult and exhausting. The unskilled speaker will pronounce and use words in unusual ways, use new metaphors and gestures, and use a syntax that does not easily match our tuned system. Thus, there will be misunderstandings, ambiguities, and the need for restatement that literally takes time and effort and may generate annoyance because the extended interaction interferes with other goals.

Again, the developmental literature provides a powerful example. Before an infant is strongly tuned to its native language, it can perceive phonetic distinctions that are not incorporated into the native language (e.g. Aslin, Jusczyk, and Pisoni, 1998; Kuhl, Williams, Lacerda, Stevens, and Lindblom, 1992). However, once the infant has had considerable experience with the native language, the ability to perceive non-native distinctions is lost (e.g. the inability of native Japanese speakers to perceive the /l/ versus /r/ distinction).

We propose furthermore that the frequency and familiarity of tuned interactions make them more accessible to reflective, discursive consciousness. Thus, these sorts of interactions can be communicated through language and endorsed to a lesser or greater degree when encountered on a survey.

In contrast with the interdependent self, we propose that the independent self arises from more varied interactions with a broader array of people, sights, sounds, and actions. Thus the independent sensorimotor system becomes less narrowly tuned to particular practices.

By way of analogy, consider the different tuning required for soccer and (American) football players. Their knowledge of the “natural” mode of conduct in their respective game cultures is fundamentally constituted by an implicit repertoire of how to engage the ball, team members (i.e. in-group), and opponents (out-groups). For example, the suppression of a reflexive motor command to handle a looming ball manually in the case of the soccer (but not football) player is a preverbal, non-ideological bodily tendency that establishes his belonging to the soccer culture.

Of course, becoming a coach necessitates acquiring some skill in communicating knowledge in the form of instructional rules. This, however, does not necessarily bring about a change in the representational format of the basic knowledge from sensorimotor to symbolic or abstract. That is, the coach may describe the rule verbally, but it requires physical practice to instantiate the rule in behavior.

Thus, contrary to the mainstream view, explicit, verbalizable value statements come secondarily to what makes up culture. From the enculturated layperson's view (when serving as a participant in a cross-cultural study), values are not the source for culture but are contingent attempts to find an abstract generalization that captures the relevant confluence of implicit bodily routines. As such, the verbal value statements conform to the underlying procedural dispositions to the extent that these are accessible to consciousness and can be verbalized.

For our account to have any force, it must be the case that social and physical environments that foster interdependent and independent selves differentially afford the sensorimotor tuning we propose. The following excerpt from Adams and Markus (2004, p. 343) suggest that is the case:

Given an exclusive emphasis on “subjective culture”, there is a tendency to interpret cultural patterns like independent and interdependent construals of self ... [citing Markus and Kitayama, 1991] as differences in subjective beliefs. Instead these concepts refer to different constructions: beliefs built into the physical patterns of everyday life. The independent constructions of self and relationship that are prominent in mainstream American settings are not merely beliefs about separation. Instead, they are linked to a reality of separation that is built into structures of everyday life like dating practices, residence in apartment units, and individual ownership. Similarly, the more relational or interdependent constructions of self and relationship that are prominent cultural patterns in many West African settings are not merely beliefs about connection. Instead, they are linked to a reality of connection that is built into structures of everyday life like arranged marriage, residence in lineage compounds and the practice of eating meals from a communal bowl.

Research on child attachment theory has also documented systematic differences in child-rearing practices between Western and Eastern settings. In Japan (Rothbaum, Weisz, Pott, Miyake, and Morelli, 2000), Cameroon (Keller, Voelker, and Yovsi, 2005), India (Saraswathi and Pai, 1997), and Mexico (Brazelton, Robey, and Collier, 1969), children are carried along in daytime and sleep next to their mothers at night. Children are watched and even breastfed by neighbors and relatives. Mothers are keen to quickly or even anticipatorily respond to their children's distress signals, which “minimizes self-other distinction” (Greenfield, Keller, Fuligni, and Maynard, 2003, p. 470).

Thus, from the birth onward, the child's sensory and motor systems are immersed in tangible socio-physical environments with a tacit predominance of either independence/individualistic or interdependence/collectivistic practices. Only (or predominantly) by virtue of their substantial incarnation in the palpable physical and interpersonal structures of the local environment do these practices gain their psychological force and appear to the researcher as an ideology. They carve a peculiar profile of sensorimotor tuning of the child's body as she strives to make sense and effectively participate in the daily behavioral “rituals” dictated by the local social and physical ecology.

In short, the account we advocate as an alternative does not stop at the assertion that culture is embodied. Rather, we understand culture, that is, sensorimotor tuning, to infuse virtually all knowledge. Culture does not have domain-specific mechanisms of its own, but works through biases in interactional sensorimotor mechanisms.

Clearly, this conception of culture raises enough empirical questions to fill several lifetimes of research. We begin by reporting on two projects that address some of those salient questions. In the first project, we ask if our conception of culture, based on tuning of sensorimotor

mechanisms, can play out in a prototypical sensorimotor task: distance estimation. In the second, we ask if close sensorimotor interaction can result in the formation of an in-group.

Project 1: culture and distance estimation

How do we estimate the distance to objects? Almost certainly, we are not born with built-in rulers that give us measures in feet or meters. Instead, we seem to use body-based rulers (Proffitt and Linkenauger, 2013): eye height provides the unit for measuring the height of an object (e.g. it's about as tall as I am), the hand is used for scaling graspable objects (I can easily grasp it), the length of the arm scales reachable objects in peripersonal space (I can reach it), and the amount of effort needed to traverse a distance is used as a measure of that distance. Thus, as reviewed in Proffitt (2006), participants reported inflated visual distance to targets that required more motor effort to reach. Similarly, participants who were wearing a backpack, exhausted, in poor fitness, elderly, or in ill-health reported hills to appear steeper when compared with their fit, healthy, younger, or rested counterparts.

We combined Proffitt's insights with our speculations about culture to generate the cultural-effort hypothesis: because it is easier to interact with in-group members than out-group members, in-group members should be seen as literally closer than out-group members. However, because sensorimotor tuning to the in-group is stronger for those with interdependent self-construals than those with independent self-construals, we predicted that the difference in distance estimation would be greater for interdependents.

In the first experiment (for details, see Soliman, Gibson, and Glenberg, 2013), Participants filled out the paper-and-pencil Singelis (1994) scales to get a measure of interdependence and independence. For example, agreeing that, "I feel good when I cooperate with others," is taken as evidence for an interdependent self-construal. We computed the ratio of the interdependence to independence scales, and we refer to this ratio as "measured interdependence." The participants practiced making distance judgments in terms of number of seconds it would take to walk to a target, namely, an experimental confederate. Finally, the participants moved to a new location and judged distances to the confederate (literal distances were between 6.77 and 22.43 meters). Importantly, the participants were American students and the confederates were American students (in-group).

Of course, judged distance (seconds) increased as a function of literal distance; on average, each meter of literal distance increased the judged distance by 0.86 seconds (see Figure 20.1). More importantly for the cultural-effort hypothesis, there was a statistically significant interaction: the more interdependent the participant, the shorter the estimated distance to the in-group confederate, and this was particularly true for the longer distances.

The fact that we observed an interaction (that the difference in judged distance between interdependents and independents increased with distance) and not simply an overall difference between interdependents and independents is important for demonstrating that the groups were using different measurement scales (Proffitt and Linkenauger, 2013). Note that when the unit of measurement differs, the difference becomes larger with increased distance (an interaction). For example, suppose that person A measures distance in feet, and person B measures distance in yards. At a distance of 1 yard, the two measurements, 3 (feet) and 1 (yard), differ by 2. But at a distance of 5 yards, the two measures, 15 (feet) and 5 (yards), differ by 10. Thus, the interaction is strong evidence that the interdependents and independents are measuring distance using different scales, namely different amounts of expected effort.

Although the data from Experiment 1 are consistent with the cultural-effort hypothesis, this novel finding needs to be replicated, it needs to be extended to other cultures, and we need to

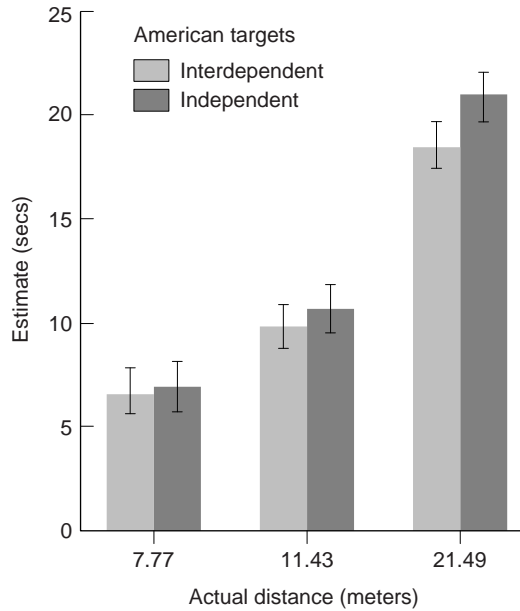


Figure 20.1 Mean estimated distance (in seconds, sec, to walk to the target) as a function of actual distance (in meters, m) for American participants judging distances to American (in-group) targets. The “interdependent” mean estimates are for one standard deviation above the mean measured interdependence; the “independent” mean estimates are for one standard deviation below the mean measured interdependence. Error bars indicate one standard error.

test additional predictions. For example, when judging distances to out-group members, we should find the reverse effect. That is, interdependents are strongly tuned to the in-group, and so interactions with out-group members should be seen as particularly effortful. For independents, who are not strongly tuned to the in-group, interactions with the out-group should not be particularly effortful. Thus, when interacting with the out-group, we predict that literal distances should appear farther for interdependents than for independents, the reverse of the data in Figure 20.1.

We tested these ideas in a new experiment that included both Arab and American participants. Our confederates were two dark-skinned women, one of whom wore a hijab (Arab head covering). The idea was to make it appear that the confederates were members of the in-group for the Arab participants and members of the out-group for the American participants.

The distance estimates are displayed in Figure 20.2. Again, there is a large increase in estimated distance with real distance (0.81 seconds/meter). In addition, there were two statistically significant interactions. The first interaction was between culture (Arab or American) and measured interdependence. For the Arabs, when judging distance to in-group members (the Arab-looking confederates), the interdependents produced smaller estimates than the independents, thus replicating the effects seen in Experiment 1, but with participants from a different culture. For the Americans, when judging distance to out-group members (the Arab-looking confederates), the interdependents produced larger estimates than the independents, thus confirming the reversal predicted from the cultural-effort hypothesis. The second interaction indicated that these effects of culture and self-construal increased with distance, replicating the interaction in Experiment 1, and strongly confirming the prediction that the groups are using different measurement scales.

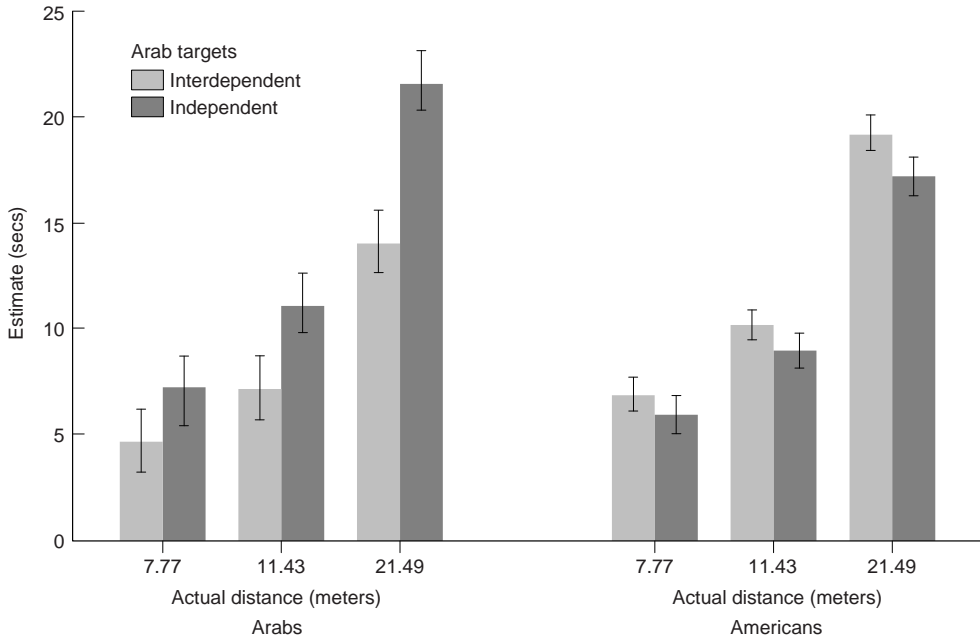


Figure 20.2 Mean estimated distance (in seconds, sec, to walk to the target) as a function of actual distance (in meters, m) for Arab participants (on the left) and for American participants (on the right). Both groups of participants judged distances to Arab-looking targets. The “interdependent” mean estimates are for one standard deviation above the mean measured interdependence (for Arab or American groups separately); the “independent” mean estimates are for one standard deviation below the mean measured interdependence. Error bars indicate one standard error.

These findings can be seen only as preliminary: it is still necessary to replicate using participants from additional cultures, and although Proffitt’s mechanism of expected motor effort seems to be a plausible cause underlying these cultural differences in visual estimates, this mechanism still needs to be directly implicated. Nonetheless, the findings are clearly consistent with the cultural-effort hypothesis in particular and with our claims about the sensorimotor nature of culture in general. They point to the possibility of redefining interdependence and independence by recourse, not to explicit values and beliefs, but to sensorimotor interpersonal repertoires that are either narrowly tuned to in-group interactional practices, or more broadly tuned, and appearing to be more culturally diverse.

Project 2: tuning the sensorimotor system and the joint body schema

An important part of our approach to culture is the idea that frequent interaction and coordination tunes the sensorimotor system in the service of efficient interaction. The first project presumed greater tuning among same-culture participants and greater tuning for interdependents than independents. In the second project, we attempt to create sensorimotor tuning and measure some of its manifestations, namely, changes in the body schema.

Primates use a body schema to track the locations of their limbs. This schema is malleable (a) because it must change with development and growth, and (b) because it adapts with tool use

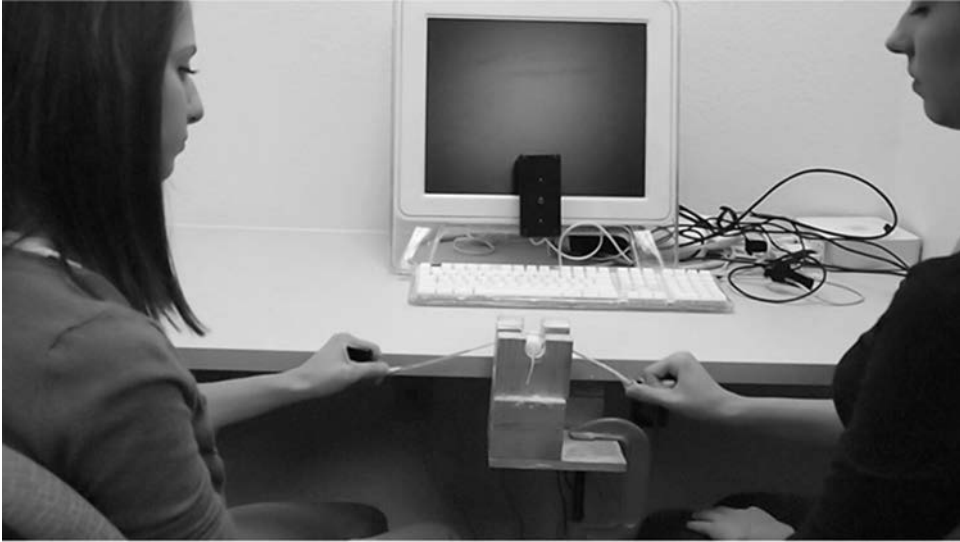


Figure 20.3 The arrangement for inducing and measuring the JBS (joint body schema) effect. The confederate, on the left, is using her left hand to help saw the candle. The participant, on the right, is using her right hand. Note that her left hand is in her lap. The candle is held horizontally in the wooden holder. The LEDs are mounted on the bottom of the screen. During the measurement phase, the confederate holds her left hand near the LEDs so that her index finger is near the top LED and her thumb is near the bottom LED.

(as reviewed below). Here we predict that adaptation of the body schema when coordinating with another person will be particularly strong among those with interdependent self-construals. That is, because interdependents have a developmental history of closely attending to (in-group) others, they should show a particularly robust adaptation of the body schema.

The experiments had two phases. In the first phase, the participant and the confederate coordinated for five minutes by moving a flexible wire back and forth to cut through candles (see Figure 20.3; for details, see Soliman, Ferguson, and Glenberg, submitted). The task required close coordination to keep the wire taut so that it would cut. In the basic experimental condition illustrated in Figure 20.3, the participant (on the right) uses her right hand to hold one end of the wire tool, and the confederate uses her left hand.

The second phase of the experiment was the flash/buzz paradigm as developed by Maravita, Spence, Kennett, and Driver (2002). Using this procedure, the participant has a cell phone buzzer attached to the index finger and another attached to the thumb. One of the buzzers is activated, and the task is to indicate (using a foot pedal) whether the thumb or index finger had been stimulated. The task is trivially easy. However, if the two fingers are held next to LEDs, and the LEDs flash in temporal synchrony with the buzzer but spatially incongruously (e.g. the thumb is stimulated by the buzzer but the LED next to the index finger is flashed), participants are slowed and make errors.

Maravita *et al.* (2002) demonstrated that tool use can modify the interference from incongruous trials in the flash/buzz procedure. Namely, before using a tool, the LEDs interfere with localization of the vibration only when they are near the fingers, that is, in peripersonal space. After using a tool (e.g. a rake), the LEDs can be located at the end of the tool, outside of the usual peripersonal space, and still interfere with localization of the active buzzer.

Maravita and Iriki (2004) review the physiological basis for this effect. In brief, there are bimodal neurons in the parietal cortex that have both somatosensory and visual receptive fields focused on the hand. That is, touching or stimulating the hand increases the firing of these neurons on the basis of the somatosensory receptive field. The same neuron also has a visual receptive field so that looking near the hand increases the firing rate of the neuron. Thus, the neuron appears to be useful for coordinating between vision and touch. Furthermore, after tool use, the visual receptive field migrates to include the effector end of the tool even if that end is outside of peripersonal space. Now the neural firing serves to coordinate the sight of the end of the tool with the feel at the hand. Thus, tool use adapts the body schema so that it incorporates the tool in the service of effective wielding.

We had two questions. First, does close coordination with another person act to adapt the body schema as if the other person were a social tool? That is, would our participants adapt their own body schemas to incorporate aspects of the partner in the service of effective coordination? Second, would this adaptation of the body schema be more pronounced for those with interdependent self-construals? If so, then after coordination in the candle-cutting task, when the in-group confederate holds her hand near the LEDs, incongruous flashes should interfere with the interdependent participant's ability to localize the buzzing stimulus on her own fingers. We refer to this possibility as the development of a joint body schema (JBS).

The experiments also examined several other constraints on the development of the JBS. First, the interference produced by the confederate's fingers near the LEDs should only be found after the confederate and the participant jointly cooperate in cutting the candle. When the participant cuts the candle herself by using a wire with a plumb weight on one end (to replace the confederate), there should be little interference produced by the confederate's fingers near the LEDs. In fact, we will use as a measure of the JBS the following difference of differences. After the participant and the confederate have coordinated in cutting the candle, we measure the time for the participant to correctly localize the buzz on her fingers when the confederate has her fingers near the LEDs. The first difference is between the mean for incongruous trials compared with the mean for congruous trials (when the flashing LED is near the confederate's finger that is homologous to the participant's finger that is stimulated). This difference indicates the interference produced by incongruous trials. We also compute the same difference after the participant has cut the candle by herself, although the confederate holds her fingers near the LEDs. The difference of the differences is produced by subtracting from the first difference (the interference effect after coordination) the second difference (the interference effect after no coordination). This difference of differences tells us whether by coordinating with the confederate, the participant has adjusted her own body schema, that is, whether the confederate has become a social tool. This difference-of-differences score is depicted on the far left in Figure 20.4, and we will refer to it as the JBS effect.

Second, if the body schema of the participant is actually affected (rather than the participant simply learning to attend to the confederate's hand), then the JBS effect should be most pronounced when the participant is buzzed on her left hand, the hand homologous to that used by the confederate in jointly cutting the candle. The JBS effect should be reduced if the participant is buzzed on her right hand. The right-hand (non-significant) JBS effect is illustrated by the bar second from the left in Figure 20.4.

Third, if the confederate uses her right hand to cut the candle, then there should be a reduced JBS effect on the participant's left hand. This non-significant JBS effect is illustrated by the third bar.

Fourth, and most relevant to the current purposes, if the participant has an interdependent self-construal, that is, her developmental history has primed her to attend closely to others, then she should

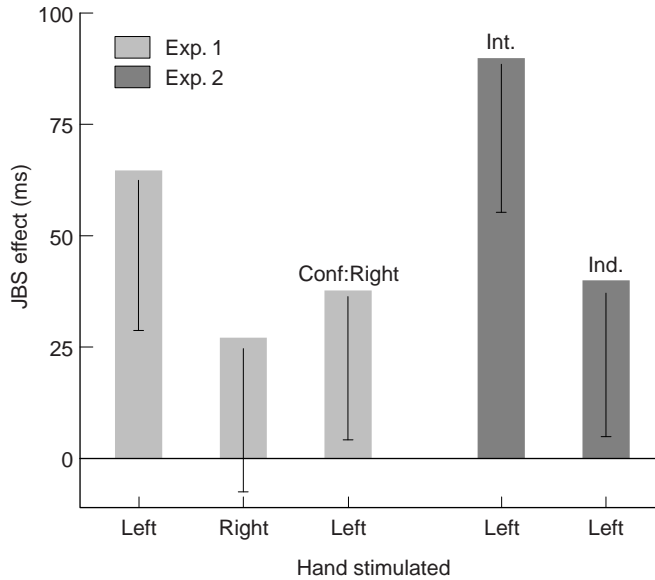


Figure 20.4 The mean JBS (joint body schema) effect (in milliseconds, ms, see text for explanation). In all conditions, the confederate held her left hand at the LED (see Figure 20.3). In all conditions except the one labeled “Conf:Right,” the confederate had used her left hand to help cut the candle. For Experiment 2 (Exp 2), the “interdependent” (Int) mean estimate is for one standard deviation above the mean measured interdependence; the “independent” (Ind) mean estimate is for one standard deviation below the mean measured interdependence. Error bars are one standard error although only the lower error bars are illustrated.

develop a large JBS effect compared to participants with independent self-construals. The statistically significant JBS effect for interdependent participants is illustrated in the fourth bar, and the non-significant effect for the participants with independent self-construals is illustrated in the fifth bar. (The data contributing to the first and fourth bars are from different participants. Thus the data provide a replication of the JBS effect across experiments; see Soliman, Ferguson *et al.*, submitted, for details.)

We think that the JBS effect is likely to be much more than a laboratory curiosity. Note that societies offer multiple opportunities for close coordination: dancing, singing, marching, praying, cooking, manufacturing. All of these opportunities can, we suspect, create multiple JBSs that become the basis for the in-group. Furthermore, we suspect that having a JBS is a precondition for a strong empathetic response. In fact, others have already demonstrated that synchronous behavior does enhance empathy. Finally, the notion of a JBS helps us to understand not just in-group favoritism, but also out-group derogation. That is, people with whom one has interacted feel close, perhaps even part of the self, because of the JBS. In contrast, people with whom one has not interacted appear distant, separate from the self, and perhaps even different in kind.

Conclusions

In this chapter, we presented the first pass of a unified sensorimotor account of culture. In place of dualistic conceptions that propose a distinction between values and behaviors, we conceive of culture as a repertoire of bodily modes of interaction. These modes develop through, and

ultimately serve, effective participation in socio-physical ecologies. In support of this view, we empirically demonstrated two effects. First, part of having an interdependent self-construal is to experience more bodily effort when interactions with out-group members loom. Second, interdependents easily adapt their own body schemas to incorporate the kinematics of an in-group partner. Being an independent, on the other hand, partly means that one is likely to experience less differential effort when interacting with in- or out-group members, and after interacting, the independent will maintain a stronger distinction between self and other. These preverbal bodily ways of relating to others, we believe, constitute the foundations of the psychological fabric of culture.

References

- Adams, G., and Markus, H. R. (2004). Toward a conception of culture suitable for a social psychology of culture. In M. Schaller and C. S. Crandall (Eds.), *The psychological foundations of culture*. Hillsdale, NJ: Erlbaum.
- Aslin, R. N., Jusczyk, P. W., and Pisoni, D. B. (1998). Speech and auditory processing during infancy. In D. Kuhn and R. Siegler (Eds.), *Handbook of child psychology: Cognition, perception, and language* (5th ed.). New York: Wiley.
- Atran, S., Medin, D., and Ross, N. (2005). The cultural mind: environmental decision making and cultural modeling within and across populations. *Psychological Review*, 112(4), 744–76.
- Brazelton, T. B., Robey, J. S., and Collier, G. (1969). Infant development in the Zinacanteco Indians of southern Mexico. *Pediatrics*, 44(2), 274–83.
- Cohen, D., Nisbett, R. E., Bowdle, B. F., and Schwarz, N. (1996). Insult, aggression, and the southern culture of honor: An “experimental ethnography.” *Journal of Personality and Social Psychology*, 70(5), 945–60.
- Dahl, A., Campos, J. J., Anderson, D. I., Uchiyama, I., Witherington, D. C., Ueno, M., et al. (2013). The epigenesis of wariness of heights. *Psychological Science*, 24(7), 1361–67.
- D’Andrade, R. (2000). The action system hypothesis. Paper presented at a colloquium given by the Committee on Human Development at the University of Chicago, May.
- Gallese, V., Keysers, C., and Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in Cognitive Sciences*, 8(9), 396–403.
- Greenfield, P. M., Keller, H., Fuligni, A., and Maynard, A. (2003). Cultural pathways through universal development. *Annual Review of Psychology*, 54, 461–90.
- Haidt, J., and Hersh, M. A. (2001). Sexual morality: The cultures and emotions of conservatives and liberals. *Journal of Applied Social Psychology*, 31, 191–221.
- Hong, Y., and Chiu, C. (2001). Toward a paradigm shift: from cross-cultural differences in social cognition to social-cultural mediation of cultural differences. *Social Cognition*, 19, 181–96.
- Keller, H., Voelker, S., and Yovsi, R. D. (2005). Conceptions of parenting in different cultural communities: The case of West African Nso and northern German women. *Social Development*, 14(1), 158–80.
- Kitayama, S. (2002) Culture and basic psychological processes – Toward a system view of culture: Comment on Oyserman et al. (2002). *Psychological Bulletin*, 128(1), 89–96.
- Kroeber, A. L., and Kluckhohn, C. (1963). *Culture: A critical review of concepts and definitions*. Cambridge, MA: Harvard University Press. (Orig. publ. 1952.)
- Kuhl, P. K., Williams, K. A., Lacerda, F., Stevens, K. N., and Lindblom, B. (1992). Linguistic experience alters phonetic perception in infants by 6 months of age. *Science*, 255(5044), 606–8.
- Maravita, A., and Iriki, A. (2004). Tools for the body (schema). *Trends in Cognitive Sciences*, 8(2), 79–86.
- Maravita, A., Spence, C., Kennett, S., and Driver, J. (2002). Tool-use changes multimodal spatial interactions between vision and touch in normal humans. *Cognition*, 83(2), B25–34.
- Markus, H. R., and Kitayama, S. (1991). Culture and the self: Implications for cognition, emotion, and motivation. *Psychological Review*, 98(2), 224–53.
- (2010). Culture and selves: A cycle of mutual constitution. *Perspectives on Psychological Sciences*, 5(4), 420–30.
- Nisbett, R. E., and Miyamoto, Y. (2005). The influence of culture: Holistic versus analytic perception. *Trends in Cognitive Sciences*, 9(10), 467–73.

- Norenzayan, A., Smith, E. E., Kim, B., and Nisbett, R. E. (2002). Cultural preferences for formal versus intuitive reasoning. *Cognitive Science*, 26(5), 653–84.
- Oyserman, D., Coon, H., and Kemmelmeier, M. (2002). Rethinking individualism and collectivism: Evaluation of theoretical assumptions and meta-analyses. *Psychological Bulletin*, 128(1), 3–72.
- Proffitt, D. R. (2006). Embodied perception and the economy of action. *Perspectives on Psychological Science*, 1(2), 110–22.
- Proffitt, D. R., and Linkenauger, S. A. (2013). Perception viewed as a phenotypic expression. In W. Prinz, M. Beisert, and A. Herwig (Eds.), *Action science: Foundations of an emerging discipline*. Cambridge, MA: MIT Press.
- Rizzolatti, G., and Craighero, L. (2004). The mirror neuron system. *Annual Review of Neuroscience*, 27(1), 169–92.
- Rothbaum, F., Weisz, J., Pott, M., Miyake, K., and Morelli, G. (2000). Attachment and culture: Security in the United States and Japan. *American Psychologist*, 55(10), 1093–1104.
- Saraswathi, T. S., and Pai, S. (1997). Socialization in the Indian context. In H. S. R. Kao and D. Sinha (Eds.), *Asian perspectives on psychology*. Thousand Oaks, CA: Sage.
- Singelis, T. (1994). The measurement of independent and interdependent self-construals. *Personality and Social Psychology Bulletin*, 20(5), 580–91.
- Smith, L. B. (2005). Action alters shape categories. *Cognitive Science*, 29(4), 665–79.
- Soliman, T., Ferguson, R., and Glenberg, A. M. (submitted). Humans develop an interpersonal joint body schema.
- Soliman, T., Gibson, A., and Glenberg, A. M. (2013). Sensory motor mechanisms unify psychology: The embodiment of culture. *Frontiers in Psychology*. doi: 10.3389/fpsyg.2013.00885.
- Sommerville, J. A., Woodward, A. L., and Needham, A. (2005). Action experience alters 3-month-old infants' perception of others' actions. *Cognition*, 96(1), B1–11.
- Swidler, A. (2001). *Talk of love: How culture matters*. Chicago: University of Chicago Press.
- Triandis, H. (1995). *Individualism and collectivism*. Boulder, CO: Westview Press.
- Tripathi, L. (2001). Culture as a psychological construct. *Psychology Developing Societies*, 13(2), 129–40.
- Vaisey, S. (2008). Socrates, Skinner, and Aristotle: Three ways of thinking about culture in action. *Sociological Forum*, 23, 603–13.
- Varnum, M., Grossman, I., Kitayama, S., and Nisbett, R. (2010). The origin of cultural differences in cognition: Evidence for the social orientation hypothesis. *Current Directions in Psychological Science*, 19(1), 9–13.

21

MORALITY IN THE BODY

Brendan Strejcek and Chen-Bo Zhong

There is a long tradition of thought that conceives of morality as in opposition to the appetites and desires of the body. Such physical experiences have, at best, been seen as distractions from the expression of values guided by reason, and, at worst, as the direct cause of sin and immorality through temptation. However, this understanding is being called into question by recent theoretical and empirical work that supports the position that the body is not only an obstacle to morality and moral action, but also a contributor to moral reasoning. Moral concepts seem to be built using mental machinery that is also used for processing bodily experiences. Empirical work in social psychology has shown how intimately these two domains are intertwined, with both reason and bodily inputs feeding back into moral judgment and moral action.

This perspective is consistent with the emerging convergence in evolutionary biology, which claims that morality evolved through the body during the process of negotiating the various pressures of selection. Understanding this reciprocal relationship between morality and body may allow one to know when bodily input may result in maladaptation with regard to our current social environment. For example, the common derogation of the outsider, once perhaps adaptive to defend against invaders and the unknown, can now have many negative side effects, especially in a mass, diverse culture; this can include prejudice, fear, or discrimination when no real danger exists.

Philosophy, reason, and emotion

Historically, there have been two influential dualisms in philosophy: the ontological body/spirit duality (sometimes framed as body/mind) and the emotion/reason duality. These dualities have had numerous forebears, from the Platonic (which actually divided the soul into three parts: appetitive, rational, and spirited) to the Christian. Though several early influential philosophers, such as Democritus and Epicurus, did not separate the functioning of the mind from the functioning of the body, throughout the story of Western philosophy, dualism has mostly been ascendant. Descartes reaffirmed this tradition in the seventeenth century at the beginning of the scientific revolution by aligning dualist rationality with scientific progress in his *Discourse on Method* (1637). The dualism of Descartes was driven by a desire to find a firm basis for a developing scientific epistemology, which was ultimately provided by the dictum “I think,

therefore I am.” Though many modern proponents of morality based on rationality do not subscribe to Cartesian substance dualism, the concept has framed the debate.

In all of these dualist conceptions, morality has been identified with reason, often in tension with the appetitive, emotional body. As such, morality has been investigated through the lens of reason. Bodily influence is even used as a mitigating factor in legal cases, as emotional influence is often seen as a loss of control or decrease in free will. For example, consider the “heat of passion” defenses. Emotional and bodily influence has thus been seen as a biasing factor in the proper expression of moral behavior. It is undeniable that sometimes emotions can motivate ethically problematic behavior, but modern cognitive science has been uncovering empirical evidence that the functioning of moral reasoning is expressed through the body using emotional cues. These cues manifest linguistically as metaphors, which have become the philosophical spur of modern embodiment research.

Metaphor

Many moral concepts are described and conceptualized through metaphors, which are often grounded in bodily experiences. Some of the key foundational physical metaphors that anchor moral reasoning include uprightness/height, balance, control/freedom of movement, health/strength, and purity (Lakoff and Johnson 1999, p. 333).

The “up” metaphor is particularly potent (associated with more, control, good, and rational). The emotion associated with being uplifted by the altruistic deeds of others is often referred to as elevation (it is almost impossible to even discuss this emotion without the assistance of metaphors). Ideas of value also have physical forebears, such as the concrete experience of ownership and quantity. Well-being is considered a form of wealth, and languages are rich with examples of accounting metaphors (cost, loss, gain) regarding happiness and the good life, and these metaphors extend to fairness, reciprocation, debt, revenge, and similar concepts. Finally, purity, corruption, contagion, health, and strength are all key terms in moral discourse and are almost synonymous with concepts of good and evil (consider the meaning of the sentence “he is corrupt,” or “she is pure”). This collection of metaphors has provided a framework for social scientists to investigate the impact of bodily and physical experience on moral judgment.

It is thought that the evolutionary experience of survival has equipped the mind with a number of concrete concepts used for day-to-day survival (more nutrition is desirable, dirty things are sources of contagion, and so forth). These concepts were then available for repurposing in a pre-adaptive fashion (Rozin, 1999). This perspective is often discussed as a form of scaffolding, as the concrete experience being scaffolded into our conceptual development (Williams, Huang, and Bargh, 2009), which informs much of the rest of the analysis below. Though the structure of metaphors may be stable across cultures, specific expression can vary dramatically across time and space (thus, the unclean may be universally associated with the malevolent, but exactly what is considered to be unclean will likely vary by culture). That is, the concrete objects that satisfy specific metaphors are malleable, but the mental subsystem of, for example, disgust/dirtiness and avoidance seem to be available to people in general.

These associations are empirically observed in our use of language, but they do not in themselves lead to the conclusion that morality is shaped by bodily experience (as opposed to just being used descriptively). To make this link, both experimental psychology and neuroscience have found that experiences of these physical metaphors can affect moral judgment and moral action in measurable, significant ways.

Social intuitionism

Instead of seeing moral judgment as the process of rational analysis, numerous studies in experimental and social psychology have found that moral judgment tends to happen quickly and intuitively and is often influenced by bodily experiences. Haidt and Hersh (2001), for example, constructed hypothetical situations designed to be socially repugnant, but not harmful in any way, to question the idea that moral judgment was carefully and rationally constructed. They found that people's affective reactions to those vignettes were much stronger predictors of moral judgment than analysis of harm and moral principle. Participants in their studies typically express strong moral opposition against disgusting but harmless acts such as a consensual kiss between siblings; when pressed to explain their moral reasoning, however, a common reaction was moral dumbfounding – strong moral condemnation with an utter inability to rationally explain their position.

The social intuitionism model proposed by Jonathan Haidt to explain this phenomenon holds that moral reasoning is retroactive, with rational processing often happening after the fact to justify and explain decisions previously determined by non-rational means. Thus, the model questions the causal power of reasoning in moral judgment. This is congruent with the perspective of embodied morality, which sees morality arising through bodily experience often expressed as emotions. These means are primarily emotional, and involve revulsion and disgust. The emotions seem to be expressed through the medium of the body and understood using the language of metaphors (Haidt, 2001).

Social neuroscience

Historically, when confronted with different explanations for moral action, the tools for investigation were limited. Epicurus conceived of the functioning of the mind as physical movements in the chest, but this was almost more of a metaphysical position derived from the earlier Presocratic atomists. Now, with fMRI machines and the beginnings of brain maps, we begin to have a better picture of what goes on in the human body when thinking happens and decisions are made.

A number of prominent studies found that the brain regions that govern emotion regulation are intimately connected to moral reasoning and contemplation (Damasio, Tranel, and Damasio, 1990; Greene, Sommerville, Nystrom, Darley, and Cohen, 2001). Different parts of the brain are active when thinking about moral dilemmas that have rationally identical outcomes but different emotional engagement. For example, one intriguing thought experiment involves two structurally equivalent dilemmas in which a runaway trolley is headed toward five people and will kill them if not stopped. This dilemma is framed in two ways, a stand-in-distance “switch” version and an up-and-close “push” version. In the switch version, the only way to save the five is to hit a switch that will turn the trolley onto an alternate set of tracks where it will kill one person instead of five; in the push version of the dilemma, the only way to save the five is to push a stranger onto the tracks from a footbridge spanning the tracks. The stranger will die, but his body will stop the trolley from reaching the others. In both cases, people decide whether it is right to kill one person to save five others. Yet most people say that they would pull the switch but not push the person.

The former response represents utilitarian reasoning – people seem to suggest that sacrificing one person to save five is the right course of action because it produces greater good; the latter response represents Kantian reasoning that emphasizes the intrinsic value of a human life and the recognition that the rightness of an action is independent of its consequences (hence the

outcome of saving five others cannot justify the killing of one). It is not hard to see that these two perspectives have irreconcilable principles: while utilitarian thinking puts the “good” before the “right,” the Kantian perspective emphasizes that what is right precedes what is good. So how could rational thinking lead simultaneously to contradictory principles? A recent fMRI study found that this inconsistent moral aversion against pushing down a person to save others may stem from increased emotional engagement (Greene *et al.*, 2001) – the horrific thought of pushing someone to his or her death is much more emotionally arousing than pulling a switch. This again shows that emotional involvement is an important contributor to moral reasoning.

But some would go even further to suggest that emotional engagement may be necessary to moral choices. This is based on research showing that brain activities during contemplation of utilitarian dilemmas resembles non-moral dilemmas (Greene *et al.*, 2001) as well as the observation that individuals with antisocial traits tend to make more utilitarian choices in moral dilemmas (Bartels and Pizarro, 2011). Thus, Bloom (2011) questioned the moral nature of utilitarian reasoning altogether in that it is based on pure calculations that are largely devoid of context and meaning. This stronger view coincides with research based on patients with brain damage to their ventromedial prefrontal cortex (vmPFC), an important brain region that is involved in emotion regulation. These patients retain full capability of rational thought and reasoning, which are the type of processes required for utilitarian reasoning, but seem to have lost emotional connection and, more importantly, the ability to adapt to social and moral conventions. Over time, these patients tend to grow more antisocial (Damasio, Everitt, and Bishop, 1996).

One underlying theory is that emotional experience guides moral judgment and decision making through a series of bodily signals labeled as somatic markers. Lacking proper somatic markers, as in the case of vmPFC damaged patients, an otherwise functional brain is unable to attach moral weight or value to outcomes effectively (Damasio *et al.*, 1996). This proposition that emotional impairment leads to moral malfunction corroborates the position that moral reasoning can’t only be the product of rationality (Lakoff and Johnson, 1999, p. 327).

Thus, research on linguistics, emotion, and neuroscience converge on the involvement of bodily experiences in moral development and reasoning. Not only do people appropriate physical concepts such as up vs. down and clean vs. dirty and recast them in social and moral terms, but also “recycle” emotions and associated brain circuitries developed for rudimentary, physical tasks in early development and survival (e.g. disgust to avoid poisonous food) to help make sense of more abstract moral situations (e.g. disgust of betrayal and cheating). In the next section, we will discuss specific bodily experiences that may inform moral judgment and decision making to demonstrate how the physical and moral domains continue to overlap cognitively, emotionally, and neurologically.

Bodily experiences that influence morality

Several specific physical experiences that are related to the primary linguistic metaphors discussed above seem to contribute in various ways to moral judgment and moral decision making. The physical experiences most potent in influencing morality are those regarding disgust and purity, but many other embodied concepts such as position, color, and interior states have weight as well.

Emotion

The emotion of disgust was originally a gustatory emotion rooted in our evolutionary past as a motivational mechanism that avoids the consumption of contaminating substances. At the basic

physical level, disgust serves as a guide for approach and avoidance, and it is obvious how to reason evolutionarily about how this function might have arisen, as it results in avoidance of external dangers (such as contamination from rotting organic matter) and enhancement of survival fitness. Disgust operates on many sensory levels, from visual to taste (which functions as a last line of defense against ingesting potentially harmful food). This low level, physical aid to behavior, rooted deeply in bodily experience, has been co-opted for use by high-level, social functions, as a guide for avoiding potential social danger such as transgressions by others (Rozin, 1999).

Many studies have been done recently in social psychology that link moral transgression and physical contamination (Rozin, Haidt, and McCauley, 1993). Physical and moral disgust seem to use brain regions that overlap within the frontal and temporal lobes (Moll *et al.*, 2002; Borg, Lieberman, and Kiehl, 2008). Additionally, similar facial expressions have been found in response to both moral and physical disgust (Chapman, Kim, Susskind, and Anderson, 2009; Rozin, Lowery, and Ebert, 1994). These studies form a good foundation for the evolutionary concept of preadaptation and the reuse of cognitive capabilities shaped first for interacting with the physical environment but later conscripted for use by moral cognition.

This has particularly interesting implications for moral judgment being affected by indirect physical stimuli, such as when an emotion is not specifically elicited by a particular target of judgment. This has been shown in studies using hypnotism (Wheatley and Haidt, 2005), ambient smell (Schnall, Haidt, Clore, and Jordan, 2008; Jones and Fitness, 2008), and gustatory experiences such as bad taste (Eskine, Kacirik, and Prinz, 2011). All of these manipulations were found to impart negative qualities from the realm of the physical to the realm of the moral. These effects probably have differing magnitudes based in individual disgust sensitivity, as Jones and Fitness (2008) found that those who are more easily disgusted by physical contaminants are also more likely to engage in harsher moral judgment.

Sensory perception

Cleanliness

Cleanliness and purity have been an important part of religious ceremony for most major world religions throughout history. Given the importance of religion in our moral code, scholars such as Haidt argue that purity and sanctity constitute a fundamental moral foundation. It is not until recently, however, that empirical research in social psychology has started to demonstrate that the bodily perception of cleanliness can be both a consequence of moral status as well as a determinant of moral judgment and behavior.

This connection between physical purity and morality has been corroborated by several experimental findings. One set of results verifies this connection by observing that morally threatening situations prompt physical cleansing much like actual, physical dirtiness. For example, the following transgressions have all been found to induce a greater desire for cleansing products: reminding people of their own, past immoral acts (Zhong and Liljenquist, 2006); leaving false voicemail messages or lying through email (Lee and Schwarz, 2010); or playing violent video games (Gollwitzer and Melzer, 2012). Though these effects are similar, and presumably activate the same underlying cognitive machinery, the effects also have unique manifestations appropriate to a particular modality. Thus, mouthwash was most desired in Lee and Schwarz's voicemail experiment, whereas hand sanitizer was more strongly desired in the case of deception through email.

The most important aspect of these findings is how the physical and moral domains overlap and spill over into each other. Because of this relationship, the way that cleanliness signals the

absence of contaminants and the way disgust alerts the body to the presence of contaminants can have moral ramifications as well. This sometimes irrational metaphorical link is nonetheless often quite potent in practice. One hypothesis based on this connection between the two domains is that not only does the immoral feel impure, but also the pure should feel moral. If that were true, then an increased sense of personal cleanliness might trigger feelings of moral superiority or moral righteousness. Cleanliness has been found in the lab to trigger feelings of moral purity (e.g. Helzer and Pizarro, 2011; Xu, Bègue, and Bushman, in press; Yan, Ding, and Yan, 2011; Zhong, Strejcek, and Sivanathan, 2010), and even proximity to symbols of cleanliness seems to affect moral standing. For example, Helzer and Pizarro measured harsher moral judgments arising from standing next to a hand sanitizer and Zhong, Strejcek, *et al.* (2010) found that feeling physically clean moralized various contested issues (such as littering and homosexuality) more harshly.

In addition to the influence of cleanliness on moral judgment, physical cleansing may also directly impact moral behavior because it alters people's moral self-image (Zhong, Strejcek, *et al.*, 2010). Thus, individuals who have transgressed are less likely to engage in compensatory and restitution behaviors if they have a chance to physically clean themselves, which serves as a symbolic means to restore moral balance. This was indeed what Zhong and Liljenquist (2006) found. In their study, participants who recalled past unethical behaviors who had a chance to wipe their hands using an antiseptic wipe were less likely to volunteer to help others compared to those who did not wash hands. Further, Reuven, Liberman, and Dar (in press) replicated this finding and found that this effect is more pronounced among patients with obsessive-compulsive disorder.

The moral appropriation of physical cleanliness can be seen dramatically throughout political and religious history. The untouchables in the Indian caste system and the Japanese Burakumin are clear examples of this tendency, and the book of Leviticus in the Old Testament, which is a guide to morality, is organized around differentiating the clean from the unclean. Purity of tradition is also central to nationalist discourse and has been used repeatedly to combat "foreign" influence or deflect anxiety onto convenient out-group scapegoats, which may be the basis of much anti-Semitism and other racial, cultural, or minority derogation (Strejcek and Zhong, 2012).

Color

Stain is another potent metaphor, connected in its physical manifestation to the experience of cleanliness at base, but also resulting in a complex visual metaphor system on its own. As any experience with mixing things of different colors will make clear, light colors are more easily besmirched than dark colors, and are thus more vulnerable to corruption or irreversible change. The structural concepts of pollution in food safety and other physical domains also map to this visual metaphor of whiteness as purity and blackness as dirt. If this visual color metaphor has moral relevance, it would be expected that various moral processing tasks would be affected by color, such as the degree to which things are judged to be good or bad.

The most basic form of this effect could be the speed of valence categorization, a type of moral Stroop effect, where incongruent visual presentation (i.e. combining white color and "bad" things) slows recognition time. In the classic Stroop effect, given the word "red" written in blue ink, it takes longer to state the actual color (blue) than if the word matches the color (such as the word "red" written in red ink). A similar effect was found based on the interaction between color and moral implication of words. In one experiment, Sherman and Clore (2009) found that hand-copying a story about an immoral action sped up reaction times for both words

written in black and immoral words. Using a similar design to Zhong and Liljenquist (2006), the same experimenters found that cleaning products were also more desirable to those showing such a moral Stroop effect, which is another suggestion that the physical and moral domains overlap.

While perception of color as related to pollution and dirt has effects based on the experience of purity, the experience of darkness and light can have independent moral impact. This is based on research showing that people seem to feel more anonymous and uninhibited when they experience dim lighting (Hartley, 1974; Karnes, 1960; Page and Moss, 1976), which enables them to engage in more unethical behaviors. In one recent experiment, participants were assigned to rooms with either bright lighting or dim lighting and were asked to engage in some decision-making tasks where they could cheat. Even though it was made clear to them that all decisions were anonymous, those in the dim room tended to cheat more than those in the well-lit room. Another experiment had participants wear sunglasses (to create the experience of darkness) or regular glasses and found that those wearing sunglasses were more likely to cheat than those wearing regular glasses (Zhong, Lake, and Gino, 2010). One might object that darkness does in fact increase anonymity. It is important to note, however, that in neither study did the lighting have anything to do with anonymity. Instead, these results seem to suggest that cues of reduced lighting create an illusionary sense of anonymity, which licensed unethical behavior. The observation that moral decision-making processes take cues from sensory perceptions of color and lighting provides further support to the somatic markers hypothesized by Damasio. If moral decisions were being made independently of physical and perceptual biases, the rational mind should easily be able to factor in the function of sunglasses, but empirically it does not seem to do so.

Taste

The experience of taste has been found to inform moral judgment in ways other than disgust. One might expect the opposite of disgust to also have effects, though in the other direction. As one test of this, researchers investigated the effect of sweetness. Specifically, in one experiment those described as liking sweet foods were judged to be more agreeable and in another experiment the preference for sweet foods was indeed associated with agreeableness. People who desired sweet foods more were also more likely to exhibit altruism in the form of intention to volunteer for clean-up efforts (Meier, Moeller, Riemer-Peltz, and Robinson, 2012). Related to taste, fishy smells have also been found to increase the sense of suspicion even to abstract things unrelated to physical or gustatory concerns, such as economic trust decisions (Lee and Schwarz, 2012). These results strengthen the case that bodily influence feeds into morality by showing associations with prosociality in addition to rejection and aversion.

Balance

Much of the Western philosophical foundations of moral codes rests upon the concept of reciprocity and justice. Both have to do with the idea of balance, whether it is in the “tit-for-tat” sense or the idea of fairness and equal rights before the law (Lakoff and Johnson, 1999). Even as early as the classical Greeks and Romans, justice was personified as a goddess bearing a scale. The dominant modern discourses about fairness also heavily make use of physical metaphors, such as the level playing field (which means that all participants operate under similar constraints), or the redistribution of benefits (so that different participants have balanced amounts of whatever

resource is limited) (Leamer, 2007). The moral relevance of physical balance may manifest in two forms.

First, metaphors of balance of accounts are often used in moral conceptualizations. Well-being is seen as a form of wealth, something you can have more or less of, and thus something that can be compared (in quantity) with others. Justice, in this formulation, is the pursuit of fairness with regard to this quantitative well-being. This also holds with regard to the handling of debts; that is, one can have a moral debt to someone that must be “paid off,” either in positive or negative senses, which is how retribution, revenge, and reciprocation play into this metaphorical scheme (Lakoff and Johnson, 1999).

Second, the experience of physical balance may tip moral judgment. The physical experience of balance seems to make abstract, conceptual metaphors such as parity and fairness more accessible implicitly. This bodily priming has been found to modify the judgment of political categories, which are often also labeled in a metaphorical (though arbitrary) way, such as the description of political philosophies as left or right. A study that shifted participants’ physical balance slightly to the left or right demonstrated a tendency to judge an unrelated political position (note the metaphorical language that must be used even to discuss the concept) either as more left wing or right wing (congruent with the experimental manipulation). Thus, what one might expect to be a purely rational determination is shaped by the physical experience of the subject. The sense of balance has also been found to affect judgment, leading to an increase in the value placed on compromise choices. The mechanism behind this observed effect was hypothesized to be a metaphorical link between the concrete, physical sensation of balance and the abstract concept of parity, which is connected to moral ideas of fairness (Larson and Billeter, 2013). As categorization of political ideas tends to have moral weight (based on whether or not the person making the judgment has sympathy for those positions), the fact that physical balance can affect that judgment seems to offer at least further tangential evidence for the impact of the body on shaping moral judgment.

Interoception

Physical experiences are not limited to the perception of external reality; they also include interior states. Disgust, in addition to a response caused by external stimuli, can also be evoked by internal states such as nausea, and nausea is in fact the primary experience that results in permanent food dislike (Rozin, 1999). Not only can the real interoceptive experience influence decisions, the perceived experience can, too. This has been studied using sensory input masquerading as internal sensations, such as with false heartbeat. For example, images were judged more attractive when accompanied by false (recorded), fast-heart-rate recordings that were presented as the subject’s own heart rate (Valins, 1966). Thus, as Valins writes, “internal events facilitate emotional behavior,” which is a sort of prelude to the more sophisticated somatic marker hypothesis. False feedback has also been used for behavioral therapy, to help alleviate irrational phobias. Specifically, avoidance behavior regarding snakes has been found to decrease when subjects were led to believe that their own internal reaction was lessened via false feedback (Valins and Ray, 1967).

A similar false feedback paradigm has also been found to affect more directly moral behaviors, such as volunteering and deception. Specifically, increased heart rate was found to increase the incidence of volunteering for a charitable cause, reduce self-interested lying, and be less morally potent in the face of rational, deliberative framing (Gu, Zhong, and Paige-Gould, 2012). Self-perception of heartbeat is hypothesized to be a somatic marker that signals situational stress and contributes to people’s decisions regarding how much moral weight to give potential actions.

Thus, it seems like moral decision making in practice requires actual physical feedback as would be experienced at the time of action, not just an abstract formulation of the stakes and options. That is, if the perspective of embodied morality advanced in this chapter were true, it would be likely that people would potentially predict different actions than they might actually take. Experimentally, people have indeed been found to predict that they would take less moral action than they actually do, because moral forecasting does not sufficiently engage the emotions due to lack of somatic feedback (Teper, Inzlicht, and Page-Gould, 2011).

Discussion and conclusion

Though the effects discussed so far have important theoretical consequences, they may also have dramatic, real-world effects. For example, there is a cliché that justice is “what the judge ate for breakfast” (as stated by Judge Jerome Frank), meaning that the mood imparted by feelings of satiety or hunger affects judgment of guilt or innocence. More formally, the philosophy known as legal realism holds that legal decisions in practice depend on much more than just the letter or intent of the law, but rather are influenced by all manner of extraneous factors, some of which may be bodily factors. A study tested this by examining parole hearings where the default decision was to deny parole. The chance of parole being granted was highest at the beginning of the day or right after a food break, and decreased gradually as the session progressed, from over 60 percent on average to barely above 0 percent right before the next break. The subject judges (all of which were experienced, with greater than twenty years of practice on average) were thus found to become more severe in parole hearings the more depleted their resources became, whether that was due to hunger or exhaustion (Danziger, Levav, and Avnaim-Pesso, 2011). The exact connections of this sort of effect to metaphor-based embodied cognition remain to be elaborated, but the potential for significant impact in diverse areas of society is clear.

It might be asked whether these effects are merely biases, errors of judgment that should be overcome given sufficient cognitive effort. However, the neuroscience findings point in another direction. Though some of these bodily influences on morality do indeed result in biases, the elimination of emotional or bodily influence would likely not have the desired effect, due to the importance of somatic markers for identifying moral action. The patients that Damasio investigated in his fMRI studies were not deficient in any way regarding rational-processing power, but lacking appropriate bodily feedback, were unable to accurately weigh moral consequences in their decision making.

Taken together, these findings create a compelling case for a strong relationship between mental activities regarding low-level, physical tasks and high-level, abstract tasks, particularly socially potent abstractions such as morality. They also create a robust empirical basis for theoretical understanding in myriad fields, from psychology to philosophy and practical domains such as law.

References

- Bartels, D., and Pizarro, D. A. (2011). The mismeasure of morals: Antisocial personality traits predict utilitarian responses to moral dilemmas. *Cognition*, 121, 154–61.
- Bloom, P. (2011). Family, community, trolley problems, and the crisis in moral psychology. *Yale Review*, 99, 26–43.
- Borg, J. S., Lieberman, D., and Kiehl, K. A. (2008). Infection, incest, and iniquity: Investigating the neural correlates of disgust and morality. *Journal of Cognitive Neuroscience*, 20, 1529–46.
- Chapman, H. A., Kim, D. A., Susskind, J. M., and Anderson, A. K. (2009). In bad taste: Evidence for the oral origins of moral disgust. *Science*, 323, 1222–26.

- Damasio, A. R., Everitt, B. J., and Bishop, D. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 351(1346), 1413–20.
- Damasio, A. R., Tranel, D., and Damasio, H. (1990). Individuals with sociopathic behavior caused by frontal damage fail to respond autonomically to social stimuli. *Behavioural Brain Research*, 41, 81–94.
- Danziger, S., Levav, J., and Avnaim-Pesso, L. (2011). Extraneous factors in judicial decisions. *Proceedings of the National Academy of Sciences of the United States of America*, 108, 6889–92.
- Eskine, K. J., Kacinek, N. A., and Prinz, J. J. (2011). A bad taste in the mouth: Gustatory disgust influences moral judgment. *Psychological Science*, 22, 295–99.
- Gollwitzer, M., and Melzer, A. (2012). Macbeth and the joystick: Evidence for moral cleansing after playing a violent video game. *Journal of Experimental Social Psychology*, 48, 1356–60.
- Greene, J. D., Sommerville, R. B., Nystrom, L. E., Darley, J. M., and Cohen, J. D. (2001). An fMRI investigation of emotional engagement in moral judgment. *Science*, 293, 2105–8.
- Gu, J., Zhong, C. B., and Page-Gould, E. (2012). Listen to your heart: False somatic feedback regulates deception. *Journal of Experimental Psychology: General*, 142(2), 307–12.
- Haidt, J. (2001). The emotional dog and its rational tail: A social intuitionist approach to moral judgment. *Psychological Review*, 108, 814–34.
- Haidt, J., and Hersh, M. A. (2001). Sexual morality: The cultures and emotions of conservatives and liberals. *Journal of Applied Social Psychology* 31(1), 191–221.
- Hartley, J. E. (1974). *Lighting reinforces crime fight*. Pittsfield: Buttenheim Publishing Corporation.
- Helzer, E. G., and Pizarro, D. A. (2011). Dirty liberals! Reminders of physical cleanliness influence moral and political attitudes. *Psychological Science*, 22, 517–22.
- Jones, A., and Fitness, J. (2008). Moral hypervigilance: The influence of disgust sensitivity in the moral domain. *Emotion*, 8, 613–27.
- Karnes, E. B. (1960). Well planned lighting is city progress. *American City Magazine*, 75(April), 104–5.
- Lakoff, G., and Johnson, M. (1999). *Philosophy in the flesh*. Chicago: University of Chicago Press.
- Larson, J., and Billeter, D. M. (2013). Consumer behavior in “equilibrium”: How experiencing physical balance increases compromise choice. *Journal of Marketing Research*, 50(4), 535–47.
- Leamer, E. E. (2007). A flat world, a level playing field, a small world after all, or none of the above? A review of Thomas L Friedman’s *The world is flat*. *Journal of Economic Literature*, 45(1): 83–126.
- Lee, S. W., and Schwarz, N. (2010). Dirty hands and dirty mouths: Embodiment of the moral-purity metaphor is specific to the motor modality involved in the moral transgression. *Psychological Science*, 21, 1423–25.
- (2012). Bidirectionality, mediation, and moderation of metaphorical effects: The embodiment of social suspicion and fishy smells. *Journal of Personality and Social Psychology*, 103(5), 737–49.
- Meier, B. P., Moeller, S. K., Riemer-Peltz, M., and Robinson, M. D. (2012). Sweet taste preferences and experience predict prosocial inferences, personalities and behaviors. *Journal of Personality and Social Psychology*, 102, 163–74.
- Moll, J., de Oliveira-Souza, R., Eslinger, P. J., Bramati, I. E., Mourao-Miranda, J., Andreiuolo, P. A., and Pessoa, L. (2002). The neural correlates of moral sensitivity: A functional magnetic resonance imaging investigation of basic and moral emotions. *Journal of Neuroscience*, 22, 2730–36.
- Page, R. A., and Moss, M. K. (1976). Environmental influences on aggression: The effects of darkness and proximity of victim. *Journal of Applied Social Psychology*, 6, 126–33.
- Reuven, O., Liberman, N., and Dar, R. (in press). The effect of physical cleaning on threatened morality in individuals with obsessive-compulsive disorder. *Clinical Psychological Science*.
- Rozin, P. (1999). Preadaptation and the puzzles and properties of pleasure. In D. Kahneman, E. Diener, and N. Schwarz (Eds.), *Well-being: The foundations of hedonic psychology* (pp. 109–33). New York: Russell Sage.
- Rozin, P., Haidt, J., and McCauley, C. R. (1993). Disgust. In M. Lewis and J. Haviland (Eds.), *Handbook of emotions* (pp. 575–94). New York: Guilford.
- Rozin, P., Lowery, L., and Ebert, R. (1994). Varieties of disgust faces and the structure of disgust. *Journal of Personality and Social Psychology*, 66, 870–81.
- Schnall, S., Haidt, J., Clore, G. L., and Jordan, A. H. (2008). Disgust as embodied moral judgment. *Personality and Social Psychology Bulletin*, 34, 1096–1109.
- Sherman, G. D., and Clore, G. L. (2009). The color of sin: White and black are perceptual symbols of moral purity and pollution. *Psychological Science*, 20, 1019–25.
- Strejcek, B., and Zhong, C. B. (2012). The perils of cleanliness. In P. Rosch and U. Simon (Eds.), *How purity is made* (pp. 57–67). Wiesbaden: Harrassowitz.

- Teper, R., Inzlicht, M., and Page-Gould, E. (2011). Are we more moral than we think? Exploring the role of affect in moral behavior and moral forecasting. *Psychological Science*, 22, 543–58.
- Valins, S. (1966). Cognitive effects of false heart-rate feedback. *Journal of Personality and Social Psychology*, 4, 400–8.
- Valins, S., and Ray, A. (1967). Effects of cognitive desensitization on avoidance behavior. *Journal of Personality and Social Psychology*, 7, 345–50.
- Wheatley, T., and Haidt, J. (2005). “Hypnotically induced disgust makes moral judgments more severe. *Psychological Science*, 16, 780–84.
- Williams, L. E., Huang, J. Y., and Bargh, J. A. (2009). The scaffolded mind: Higher mental processes are grounded in early experience of the physical world. *European Journal of Social Psychology*, 39, 1257–67.
- Xu, H., Bègue, L., and Bushman, D. (in press). Too fatigued to care: Ego depletion, guilt, and prosocial behavior. *Journal of Experimental Social Psychology*.
- Yan, Z., Ding, D., and Yan, L. (2011). To wash your body, or purify your soul: Physical cleansing would strengthen the sense of high moral character. *Psychology*, 2, 992–97.
- Zhong, C. B., Lake, V. B., and Gino, F. (2010). A good lamp is the best police: Darkness increases dishonesty and self-interested behavior. *Psychological Science*, 21, 311–14.
- Zhong, C. B., and Liljenquist, K. A. (2006). Washing away your sins: Threatened morality and physical cleansing. *Science*, 313, 1451–52.
- Zhong, C.-B., Strejcek, B., and Sivanathan, N. (2010). A clean self can render harsh moral judgment. *Journal of Experimental Social Psychology*, 46, 859–62.

BODY AND EMOTION

Michelle Maiese

Introduction

Emotional consciousness, broadly construed, includes occurrent emotions, less focused emotional states (moods), long-standing emotions, background “existential orientations” (Ratcliffe, 2008), and particularly stable emotional tendencies (character traits). These modes of emotional consciousness are how minded persons like us *care* (Frankfurt, 1988), and all should be understood as essentially embodied, enactive appraisals. When I say that emotions are essentially embodied, what I mean is that the living body and its corresponding neurobiological dynamics play a constitutive rather than a merely causal role in emotional experience. And when I say that emotions are enactive, what I mean is that they are ways of engaging with and making sense of the world.

While other embodied appraisal accounts of emotion imply that emotional intentionality generates neurobiological processes that are distinguishable and separable from associated feelings, my account says that the bodily changes and affectivity that emotions involve (their feeling component) cannot be separated from their element of appraisal (their evaluative component). Indeed, insofar as bodily feelings play a key role in generating meaning, appraisal and bodily processes are *constitutively interdependent* (Colombetti, 2007, p. 543). Once appraisal is understood as distributed over a complex network of brain and bodily processes, and as thoroughly corporeal, emotion then can be characterized as a sense-making faculty of the whole embodied and situated organism (Colombetti, 2011). This active, dynamic, fully embodied process of appraisal is what I call “affective framing.”

What implications does this conception of emotion have for traditional cognitive science? It appears that emotion and our immediate capacity for detecting relevance and value is “physically grounded” in our bodily form, structure, neurobiological dynamics, and the fact that the human body as a whole is an autonomous, autopoietic system. Moreover, the detection of relevance involved in affective framing appears to be non-deliberative and non-algorithmic and to require bodily attunement and habitual patterns of bodily response. This hypothesis challenges classical cognitive science, which holds that it is possible to formulate abstract, “explicitly specifiable rules of thought” that govern the move from one cognitive state to another (Anderson, 2003, p. 94).

Essentially embodied emotions

Emotions can serve as privileged tools in the attempt to integrate the mind and body, both because they are simultaneously mental and bodily, and also because the body occupies a central place in an adequate account of emotional experience (Colombetti, 2007, p. 529). Recent work on the neurochemistry of human emotions strongly suggests that the vital systems centrally causally involved with and embodying our basic emotions are gut-based and not rooted in the brain alone.¹ Anger, for example, clearly is embodied in facial and postural changes, as well as in readiness activation, and also in complex autonomic physiological changes, including skin conductance, cardiopulmonary changes, and musculoskeletal changes (Varela and Depraz, 2005, p. 68). Emotional experience is closely bound up with feelings of various bodily changes, including racing hearts, quickened breathing, grimacing faces, tensing muscles, tingling skin, and sweating palms. These feelings often are not clearly localizable, but are instead diffusely spread out and lived *in and through* one's body as a whole. In the midst of emotional experience, we often are literally "moved" or "shaken" (Slaby, 2007, p. 432).

Of course, the claim that emotions are causally dependent on the body is fairly uncontroversial. My thesis, on the other hand, is more radical: emotional consciousness is *constitutively dependent* on our living bodies. This is because crucial structural aspects of emotion are physically grounded in the autopoietic processes and neurobiological dynamics of living organisms. The term "autopoiesis" was coined by Francisco Varela and Humberto Maturana in 1971. Influenced by philosophers such as Heidegger, Husserl, and Merleau-Ponty, these theorists sought to explore the biological basis of consciousness. In simplest terms, autopoiesis is the process whereby the constituent processes of living systems "produce the components necessary for the continuance of those same processes" (Thompson, 2007, p. 98). An autopoietic unit is a system that is capable of sustaining itself due to an inner network of reactions that regenerate the system's components. Thanks to its metabolic network, a cell continually replaces the components that are being destroyed, including its membrane, which in turn produces its own components, in an ongoing circular process. Although autopoiesis initially was limited to cells, Thompson's (2007) work explores how higher forms of life are *autonomous* agents that actively generate and maintain their own coherent patterns of activity. These thermodynamically far-from-equilibrium systems exchange matter and energy with their surroundings so as to regulate and control themselves. The constituent processes in such systems (a) recursively depend on each other for their generation and realization as a network, (b) constitute the system as a unity, and (c) determine a possible range of interactions with the environment (Thompson, 2007, p. 44).

Because a living organism always has to make sense of the world and supplement the autopoietic process with what it lacks in order to remain viable, stimuli acquire meaning to the extent that they relate positively or negatively to the "norm of the maintenance of the organism's integrity" (p. 70). A norm of maintenance can be understood as an organism's optimal conditions of activity and its proper manner of realizing equilibrium within its environment. *Adaptivity* is a matter of being tolerant to changes by actively monitoring perturbations and compensating for them (p. 147).

Key structural features of emotion are physically grounded in the autopoietic identity, self-maintenance, and adaptive sense-making of living beings. First, emotions are characterized by *conative affectivity*, which might be understood as the "experiential" aspect of consciousness, or what some theorists have described as "qualitative feel." Affectivity is linked to a creature's valenced bodily feelings or *felt needs*, whether real or merely imagined, and those felt needs help constitute "what-it-is-like-to-be" that creature. Varela and Depraz (2005) describe valence as "the primordial constitution of self-affection as a dynamic polarity, as manifesting itself in the

form of a tension that takes several forms: like-dislike, attraction-rejection, pleasure-displeasure” (p. 70). No doubt emotions are prime examples of experiential states that are phenomenologically salient, hedonically valenced, and bound up with bodily feelings of pleasure and displeasure. While anger involves the sense that one’s felt needs have been violated, joy involves the sense that one’s desires have been fulfilled. Insofar as the primary condition of life is one of want, conative affectivity arises at a basic level out of vital significance, which is rooted in biological autonomy. The constant regenerative activity of metabolism endows life with a minimal “concern” to go on living, so that the environment becomes a place of attraction or repulsion. Spinoza called this concern *conatus*, which he understood as the effort and power of life to preserve itself (Thompson, 2007, p. 155).

Emotions also are *egocentrically* structured in the sense that they are a matter of relating things in one’s surroundings to an inner source-point. Egocentricity can be understood in relation to the subject-object status of the body, whereby the body serves as both the source and target of affection. The body functions as the “zero point” in relation to which objects of perception are situated and take on meaning, and from which action proceeds, so that the ego is located wherever the body is located. In cases of anger, for example, it is in relation to me and my own vantage point that objects or events appear as violations of felt needs and as “offenses” against me or someone I care about; and it is *I* who have been involuntarily provoked and must deal with or correct the situation. This sense of one’s body as the “ego-pole” or “zero point” (Thompson, 2007, p. 29) for conscious experience is grounded in one’s living bodily dynamics. Autopoiesis entails the production and maintenance of a dynamic identity (a bodily self) in the face of material change in the environment. Autonomous systems endogenously create and maintain the constraints that modulate the constitutive processes of the system, and thereby produce their own boundary. The origin of life itself can be understood as “the transition from a chemical environment to a self-produced identity which can give a point of view that is the very origin of sense and meaning” (Varela and Depraz, 2005, p. 72). In an effort to go on living, an adapting, self-sustaining organism establishes a pole of internal identity in relation to a pole of an outside world.

The egocentric frame of reference involved in emotion also is a *spatial* frame of reference. Importantly, this spatial framework does not correspond precisely to objective measurements, but instead is a body-centered, perspectival framework in which the body functions as an indexical “here.” Objects are perceptually situated and positioned, either to facilitate or to thwart my desires, by virtue of their orientation in relation to my body. In anger, I experience myself as *uniquely located*, or *uniquely positioned*; and even though my anger often is directed toward things in the world, it radiates out from my body, so that my anger always is experienced *here*. The living body not only takes a single path through space, but also serves as the spatial point of origin for all emotional experience. This too comes about through autopoiesis and the self-production of a boundary between inner and outer. Autopoietic organization is characterized by “a peculiar circular interdependency between an interconnected web of self-generating processes and the self-production of a boundary, such that the whole system persists in continuous self-production as a spatially distinct individual” (Thompson, 2007, p. 101). This boundary is not simply a container for its constituent processes, but also is itself produced and maintained by those very processes. This spatial individuation establishes the organism as a unity in space, which is part of what it means to be an autonomous system whose concern is survival.

Emotional consciousness also is necessarily *temporal*. Caring about things always involves a sense of being anchored in the past, situated in the present, and looking toward the future. Anger, for example, has the “retention-primal impression-protention” structure that has been explored so extensively by phenomenologists. In primal impression, the conscious subject is

affected; retention holds on to past, elapsed phases of experience; and protention describes how emotional consciousness is directed forward in time. In anger, one experiences oneself as embedded in time in relation to the past (when an offense occurred) and the future (when one may avenge oneself). The flow of emotional experience is rooted in one's interests and desires, forward moving, and motivationally structured (p. 362). This necessary temporality of emotional consciousness emerges out of the dynamics of autopoietic systems. At a basic biological level, metabolism propels life beyond its present condition and toward a future time when the organism's needs might be satisfied. At a higher level, among living animals, this temporal orientation is bound up with the capacity for movement. The emergence of the living present is rooted partly in "motion dispositions" (e.g. facial expressions, gestures, and autonomic components), which signify readiness for action (Varela and Depraz, 2005, p. 69). Even more clearly, this forward trajectory manifests as the "I can" in motor intentionality. Part of the experience of the "flow of action" is a sense that one's situation deviates from some optimal body-environment relationship, and that one's intentional activity will take one closer to that optimum. The forward-looking and forward-moving behaviors of living animals thus serve as an expression of life's immanent purposiveness (Thompson, 2007, p. 362).

Now, all of these structures of emotional experience are interrelated, and all are bound up with what it means to *care*. Experiencing oneself as an inner source-point that both makes its mark on and is impacted by the world requires that one be invested in one's well-being and survival; and experiencing oneself as located in space and oriented toward future possibilities presupposes a basic level of concern about oneself. Insofar as these structures of emotional consciousness are rooted in a conative, biological impulse to regenerate and go on living, the autopoietic and metabolic processes of living organisms serve as the basic ingredients of the "natural matrix" of emotion. Of course, this is not to say that autopoiesis or the basic biological dynamics of living organisms on their own entail the emergence of full-blown emotions. Instead, these dynamics lay the foundation for emotional experience.

Embodied, enactive appraisal

One structural feature of emotion that I have not yet mentioned is their *intentionality*. Intentionality commonly is characterized either as the ability of consciousness to direct itself at or towards objects, actions, events, or itself (intentional targets), or else as the fact that conscious mental states are "about" something or another. Here I adopt the classical phenomenological view of intentionality (common to the work of Brentano, Husserl, early Heidegger, early Sartre, and Merleau-Ponty) which says that all intentionality necessarily involves (i) mental episodes (*acts* or *states*); (ii) mental topics or *objects*; and (iii) shareable mental ways of representing those objects, or *contents*. In my view, not all intentionality involves determinate or explicit content, though all intentionality does involve directedness.

Theorists often characterize the intentionality of emotion in terms of appraisal. Much of emotion theory assumes that such appraisal takes place in the head, and that bodily events and arousal count simply as an "objective index of emotion" rather than as a process of lived bodily experience (Colombetti, 2007, p. 529). Classical cognitivist theories, for example, hold that emotions are nothing but certain kinds of belief-desire pairs or evaluative judgments. However, given that someone can experience an emotion without any sort of corresponding belief, it is a mistake to think that the intentional content of emotion must be understood as the content of a judgment or as the object of a propositional attitude. Because the intentionality of emotions is neither reducible to nor requires the intentionality of belief or thought, some theorists have argued that emotional intentionality has more in common with sense perception. Roberts

(1984), for example, proposes “construal” as an alternative to judgment; Doring (2003) recommends that we understand an emotion’s motivational force in terms of “affective perception”; and Goldie (2000) notes that while it is possible to recognize something as dangerous without feeling fear, there is a special affect-charged way of recognizing something as dangerous (“feeling-toward”) that does entail fear. The various quasi-perceptual accounts of emotion rightly acknowledge that emotions focus attention, and also that the content of an emotion need not be propositional. However, such accounts do not adequately address the body’s crucial role in appraisal.

The so-called embodied appraisal theories aim to provide an account of emotional intentionality in which the body does assume center stage. For example, in his later work, Solomon (2003) maintains that emotional experiences can be understood as intentional states directed towards the condition of one’s body. In his view, bodily events are *by-products* of appraisal, and do not contribute to the elicitation of the emotion. Similarly, according to Damasio’s (1994) somatic feeling theory, while the evaluative process is very much a part of the emotion, this process is separate from feeling. The evaluative process comes first, followed by a certain neurobiological state on which an emotion supervenes, and then a feeling. Sizer (2006) likewise suggests that emotion responses (changes in the body and brain) and emotional feelings (conscious experiences of emotion) are two distinct events, and that bodily changes involved in emotion can be separated from affectivity and feeling. Finally, while Solomon, Damasio, and Sizer all maintain that emotional intentionality comes first and is followed by bodily changes, Prinz’s (2004) embodied appraisal theory claims that bodily responses come first and then emotional intentionality comes along subsequently to monitor these bodily changes. In his view, emotions are not cognitive appraisals, but rather mental states that detect bodily changes, represent objects and events as having some bearing on one’s interests, and thereby track organism–environment relations.

Of course I welcome the proposal that emotions and embodiment are closely linked and that many emotions involve characteristic bodily changes. However, the different accounts of the appraisal-body relation outlined above would lead one to believe that emotional intentionality generates neurobiological processes that are separable from associated feelings, and that physiological processes have little or nothing to do with the experiential character of appraisal. By identifying emotional feelings with bodily symptoms or manifestations, these theories imply that feeling has at best a secondary role in emotional experience. However, to suppose that affective feeling is simply a matter of our awareness of bodily changes that occur *after* appraisal has taken place is to adopt a very narrow view of emotional feelings.

To devise an account that brings together the bodily nature of emotions with their world-directedness (Ratcliffe, 2008, p. 26) and makes sense of how appraisal and bodily feelings are *constitutively interdependent*, we must abandon a disembodied conception of cognition. This account should acknowledge that our capacity to understand our surroundings is essentially bodily and affective, and capture how the constitution of meaning involved in appraisal depends on the relationship between body and environment (Northoff, 2008, p. 72). Rather than being the object of conscious awareness, a particular bodily condition is lived through in the very process of evaluating one’s environment, so that emotions count as a bodily sensitivity to what is significant (Colombetti, 2007, p. 543). This emotional attunement helps to anchor us in the world and makes the objects and situations we encounter intelligible by virtue of the fact that they somehow *matter* to us. The “lived body” and its relationship to the environment thereby serve as the constitutive basis of personal significance and meaning (Northoff, 2008, p. 70).

Like the other structural features of emotion, intentionality is rooted in the biological dynamics of living organisms. An entity that is capable of staving off its own dissolution

develops a concerned point of view, from which the world's events can be partitioned into the favorable, the unfavorable, and the neutral. Physical and chemical phenomena in and of themselves have no particular significance, but only take on meaning in relation to the "natural purpose" of living organisms to maintain their identity. As self-organizing, autonomous, dynamic systems, organisms *enact* meaning via continuous reciprocal interaction with their environments (Thompson, 2007, p. 79). However, to say that emotions are enactive is not to say that embodied action *constitutes* emotional content, but rather that dynamic bodily engagement is *a necessary condition* of emotional consciousness. The cognitive-emotional interpretations that constitute affective appraisal are physically grounded in "organismic processes of self-regulation aimed at sustaining and enhancing adaptive autonomy in the face of perturbing environmental events" (Thompson and Stapleton, 2009, p. 27). Sense-making therefore can be understood as a "bodily cognitive-emotional form of understanding" that is present in at least a protoform in all living systems (Colombetti, 2011). Of course, among complex living organisms like us, these engagements with the environment take on an especially sophisticated form. At the level of living animals, emotion emerges as "a form or structure of comportment, a perceptual and motor attunement to the world" (Thompson, 2007, p. 80) whereby an organism shapes its world into a meaningful domain.

What I call "affective framing" is the process whereby we interpret persons, objects, facts, states of affairs, ourselves, etc., in terms of *embodied desiderative feelings* (i.e. feelings of caring). A frame is a cognitive short cut that people rely on in order to attend to and highlight particular features of their surroundings, and which thereby carves out the "starting points" for deliberation, thought, and other cognitive processes. The term "affective framing" is meant to capture the idea that affectivity permeates our interpretations and patterns of attention and thereby enables us to make sense of the world. It is important to note that although I am borrowing the term *framing* from the field of cognitive science, I am not using the term in its usual way. According to the intellectualist tradition of Plato and Descartes, thought can be treated as a kind of computation. Computer programs are algorithms, and if we are computers, then it must be possible to uncover what sort of program we are running to perform various cognitive tasks. However, if this is the case, it seems that even a relatively straightforward cognitive task like playing a game of chess presents a daunting computational challenge.

As Dreyfus (2007) understands it, the frame problem has to do with recognizing significance, "knowing which facts [are] relevant in any given situation," and being able to identify the relevant modifications when the context or state of the world shifts (p. 248). The chess player must select, from among an astronomically large number of possible moves, the single move that brings her closer to victory (Noë, 2009, p. 104). This requires that the player form an accurate representation of the state of play, calculate the consequences of possible moves, and then select the move with the greatest strategic advantage. However, a *competent* player "does not face the computational problem of evaluating moves from among the potential infinity of possibilities," given that the moves worth considering seem already to be carved out in advance (Noë, 2009, p. 105). Rather than deliberating or applying some algorithm, she selects moves partly based on what "feels right."

In its most basic form, affective framing involves a low-level mode of appraisal that has to do with "ecological significance to the organism" and involves schematic evaluation that is spontaneous, automatic, and below the threshold of awareness (Northoff, 2008, p. 89). This primitive sort of evaluation allows the organism to appraise the environment in terms of survival and well-being, "thereby singling out what matters to and concerns the organism and what is of significance to it" (Northoff, 2008, p. 89). Affective framing in this way exemplifies the deep continuity between emotion and life, and how personal significance and value are linked to an

individual's lived bodily dynamics. An affective frame operates as a gut-driven short cut whose interpretive focus is targeted and contoured by a creature's embodied desires and cares. This pretheoretical, non-intellectual understanding of where to direct one's attention in a given context is built up through learning and one's embodied interactions with the surroundings. Built-up affective framing patterns come to constitute one's basic "affective orientation," which "conditions and circumscribes the kind of cognitive engagement one is able to have with the world" (Ridley, 1997, p. 174). Affect operates as the *allure* of consciousness, and implies a "dynamic gestalt or figure-ground structure" whereby some objects emerge into affective prominence, while others become unnoticeable (Thompson, 2007, p. 374). Allure operates prior to conceptual information processing, and yields a *pre-reflective*, fine-grained, *caring-contoured* mapping of one's surroundings, so that one can immediately focus one's cognitive attention. This serves to directly bias the competition for processing resources in favor of information one *feels* is important.

Affective framing explains how, depending on their emotional condition, subjects attend to different features of their environment and form different interpretations of their situation. Because our framing of a situation, person, or object is always infused with affect, feeling and appraisal are intrinsically linked. While the prefrontal lobe no doubt plays a crucial role, the provision of affective and motivational color or tone to events and situations is not simply a neural achievement. Affective framing is best understood as distributed over a complex network of brain and bodily processes; it engages not just neural circuitry, but also metabolic systems, endocrine responses, musculoskeletal changes, and cardiovascular responses.

Conclusion: implications for orthodox cognitive science

My claim that emotions are essentially embodied, enactive appraisals has important implications for artificial intelligence (AI). Much of the work being done in AI begins with the notion that it is possible to formulate "explicitly specifiable rules of thought" that govern the move from one cognitive state to another (Anderson, 2003, p. 94) and then program these rules into a computer. Early work in AI and robotics often involved robots operating in mostly static environments that to some extent had been designed specifically for them. In the real world, however, things change. To be truly "intelligent," a robot must be able to cope and adjust its plan of action, and thus be truly *dynamic* and immediately sensitive to change. However, the robot should not have to replan as a result of every change to its surroundings, but instead only in response to changes that are *relevant* to its goals. It seems clear that this ability to detect relevance is a crucial aspect of human intelligence, but it is unclear how to get a robot to accomplish this simply by following an algorithm. Programming many thousands of facts into the computer hardly helps, since effective agency requires that the computer determine which facts are relevant to its proposed action. Even if the computer had a straightforward set of relevance rules, it is unclear that it could apply these rules successfully in any efficient way. What is relevant is constantly changing, based on the interplay between various aspects of the environment, situational factors, and the robot's particular abilities. Changing any one factor can change the relevance of some other factor. Carried out by a computer system manipulating formal symbols, all this rule-following would take too long and would be too cognitively "expensive" (p. 97). Moreover, it seems that "in order to identify the possibly relevant facts in the current situation one would need a frame for recognizing," but this would result in a "regress of frames for recognizing relevant frames for recognizing relevant facts" (Dreyfus, 2007, p. 248). Without an immediate, intuitive means of detecting relevance, robots could respond only to fixed features of their surroundings.

Creatures like us seem to have some other way of recognizing and “responding directly to relevance so that the frame problem does not [ever even] arise” (Dreyfus, 2007, p. 263). Appealing to the work of Merleau-Ponty, Dreyfus proposes that the body and world are coupled in a way that allows ordinary subjects to avoid the frame problem. Human intelligence is grounded in and ultimately dependent upon a more basic way of coping, which is rooted in a feedback loop between an embodied agent and the perceptual world, and shared by many non-human animals. Experience presents the subject with more and more finely discriminated situations, on the basis of which her responses are adapted and refined. This everyday coping with the world requires that embodied beings “take as input energy from the physical universe and respond in such a way as to open them to a world organized in terms of their needs, interests, and bodily capacities” (p. 251). During such activity we are in a sense *one with the world*, rather than being one step removed from objects in our surroundings in order to think about them or represent them. We are engaged in a steady flow of activity, during which our body serves as a “grouping of lived-through meanings” that steers us toward some optimal body-environment relationship (Merleau-Ponty, 1962, p. 153). Our being appropriately sensitive to relevance “depends on our responding to what is significant for *us* given our needs, body size, [and] ways of moving,” as well as personal and cultural factors (Dreyfus, 2007, p. 265). Thus, in order to create a robot that is responsive to the significance of the environment *as it shows up for human beings*, our program would have to include a model of a body much like ours with similar needs, desires, interests, and ways of moving. Dreyfus asserts that supercomputers programmed with detailed descriptions of human bodies and motivations have little chance of being realized in the real world. I agree, but in my view this is because our capacity for detecting relevance is even more deeply grounded in our physical embodiment than Dreyfus describes.

As Anderson (2003) notes, the notion of “physical grounding” (p. 102) is at the core of intelligence and crucial for solving the “frame problem.” Our immediate capacity for detecting relevance and value is “physically grounded” in our bodily form, structure, and neurobiological dynamics. Living organisms interpret environmental stimuli in terms of their “vital significance,” and among animals, this is essentially constrained by bodily form, internal structure, bodily based capacities, and the way they are structurally coupled with the environment. Generally speaking, environmental stimuli take on the meaning that they do because we are self-regulating biological organisms that seek to survive in the surrounding natural and social world. No doubt detecting relevance and significance in a complex world such as ours goes well beyond mere survival and self-maintenance, and has much to do with *adapting* and *faring well* in a specific sociocultural context. Learning no doubt plays a huge role, so that over time we develop habitual patterns of bodily response and become selectively attuned to certain aspects of our surroundings.

I have suggested that detecting relevance and significance is a matter of bodily attunement and the built-up patterns of feeling and response that comprise affective framing. This is made possible by the fact that living creatures are dynamical and adaptive beings that interact with their environment through exchanges of matter and energy. Value-driven *points of view* emerge, orderly pattern and structure appear, and lived bodily dynamics come to exhibit certain characteristic patterns. Brain and body are interdependent and mutually regulating, and as an animal interacts with the environment, a global pattern of distributed, coherent bodily activity comes to govern its sense-making activities. Affective framing, which is rooted in neurobiological dynamics, selectively attunes living organisms to their environment and allows them to recognize which factors are relevant given their specific needs and current situational factors (Dreyfus, 2007, p. 265).

To the extent that robots fail to exhibit the dynamics of living systems, they are not self-regulating, autonomous agents, and their sense-making is not physically grounded in autopoietic and metabolic processes. Thus, there is good reason to think that they cannot have emotions like ours and are incapable of making sense of their surroundings via affective framing. This inevitably makes their ways of interpreting their surroundings very different from the sense-making that creatures like us carry out on a regular basis.

Note

- 1 See e.g. Damasio, 1999; and Prinz, 2004.

References

- Anderson, M. (2003). Embodied cognition: A field guide. *Artificial Intelligence*, 149, 91–130.
- Colombetti, G. (2007). Enactive appraisal. *Phenomenology and the Cognitive Sciences*, 6, 527–46.
- (2011). Enaction, sense-making, and emotion. In J. Stewart, O. Gapenne, and E. Di Paolo (Eds.), *Enaction: Towards a new paradigm for cognitive science*. Cambridge, MA: MIT Press.
- Damasio, A. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York: Avon Books.
- (1999). *The feeling of what happens: Body and emotion in the making of consciousness*. San Diego: Harcourt.
- Doring, S. (2003). Explaining action by emotion. *Philosophical Quarterly*, 53, 214–30.
- Dreyfus, H. (2007). Why Heideggerian AI failed and why fixing it would require making it more Heideggerian. *Philosophical Psychology*, 20(2), 247–68.
- Frankfurt, H. (1988). *The importance of what we care about*. Cambridge: Cambridge University Press.
- Goldie, P. (2000). *The emotions: A philosophical exploration*. Oxford: Clarendon Press.
- Merleau-Ponty, M. (1962). *Phenomenology of perception* (C. Smith, Trans.). London: Routledge.
- Noë, A. (2009). *Out of our heads: Why you are not your brain and other lessons from the biology of consciousness*. New York: Hill & Wang.
- Northoff, G. (2008). Is appraisal “embodied” and “embedded”? *Journal of Consciousness Studies*, 15(5), 68–99.
- Prinz, J. (2004). *Gut reactions: A perceptual theory of emotion*. New York: Oxford University Press.
- Ratcliffe, M. (2008). *Feelings of being: Phenomenology psychiatry, and the sense of reality*. New York: Oxford University Press.
- Ridley, A. (1997). Emotion and feeling. *Supplement to the Proceedings of the Aristotelian Society*, 71(1), 163–76.
- Roberts, R. (1984). Solomon on control of emotions. *Philosophy and Phenomenological Research*, 44, 395–403.
- Sizer, L. (2006). What feelings can't do. *Mind and Language*, 20(1), 108–35.
- Slaby, J. (2007). Affective intentionality and the feeling body. *Phenomenology and the Cognitive Sciences*, 7, 429–44.
- Solomon, R. (2003). *Not passion's slave: Emotion and choice*. Oxford: Oxford University Press.
- Thompson, E. (2007). *Mind in life: Biology, phenomenology, and the sciences of the mind*, Cambridge, MA: Belknap Press.
- Thompson, E., and Stapleton, M. (2009). Making sense of sense-making: Reflections on enactive and extended mind theories. *Topoi*, 28, 23–30.
- Varela, F., and Depraz, N. (2005). At the source of time: Valence and the constitutional dynamics of affect. *Journal of Consciousness Studies*, 12(8), 61–81.

23

EMBODIED EMOTION CONCEPTS

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What are emotion concepts? The answer to this question is the topic of the present chapter. We begin with the observation that people possess the concepts of “joy,” “sadness,” and “fear,” among others, as indicated by their language use and their behavior (e.g. Russell, Lewicka, and Nitt, 1989). They also recognize perceptual input from other people, such as their faces and bodies, as meaning that those people feel “joy” and “sadness” and “fear.” This chapter is about the representation of emotion concepts. What allows individuals to judge a face as expressing “disgust,” and what happens when they identify the word “cruel” in a text?

The first section of the chapter reviews ways in which these kinds of everyday, non-scientific emotion concepts have been characterized in the psychological literature (Niedenthal, 2008). After briefly describing dimensional, semantic primitives and prototype accounts and the semantic network model, as well as the assumptions upon which these accounts are based, we present an alternative account – embodied emotion concepts. An embodiment account and supporting empirical evidence will be discussed in greater detail. We conclude that an embodied or simulation account of emotion concepts provides solutions to a number of problems, or at least open questions, specific to the issue of how emotion concepts are represented, which prior accounts do not adequately address.

Semantics of emotions

Theories of emotion concepts have developed along two different lines. One line focuses on the conceptual structure of emotions as represented by words used to describe them (e.g. Ortony, Clore, and Foss, 1987; Shaver, Schwartz, Kirson, and O'Connor, 1987). The questions that arise there include: What are the dimensions of similarity that bind emotion knowledge? What are the underlying factors? The most well-known account of emotion concepts in this line is the dimensional approach, in which the underlying structure of emotion concepts is derived from peoples' judgments about their subjective feeling states. By analyzing such judgments with statistical scaling methods, researchers have hypothesized two bipolar dimensions (e.g. Barrett and Russell, 1999; Lang, Bradley, and Cuthbert, 1990; Mayer and Gaschke, 1988; Reisenzein, 1994). The two dimensions are the degree to which an emotional state is *pleasant* versus *unpleasant* (or positive versus negative) and the degree to which an emotional state is *activated* versus *deactivated* (roughly, having high versus low arousal). Thus, the fundamental understanding that

people have about emotions involves the degrees of pleasantness and activation that typically characterize them. For example, “anger” is conceptualized as highly unpleasant and moderately activated, and “fear,” as moderately unpleasant and highly activated (e.g. Russell and Barrett, 1999).

Importantly, analysis of judgments of emotions with methods of scaling does not reveal anything about representation. A passive assumption is that emotion knowledge is represented as lexical entries, or words that stand for experienced information. Two other approaches, the semantic primitives and the prototype analyses, attempt to explain difference, rather than similarity, in conceptual content between emotions. Rather than identifying the fundamental dimensions underlying the structure of emotion knowledge, these two additional accounts try to specify the conceptual content for a theoretically predetermined set of differentiated emotions.

The construction of lists of semantic primitives for emotions is a bootstrapping, bottom-up activity that involves the generation of possibilities and the attempt to define as many concepts as possible, independent of a specific language, and without adding more concepts. According to Wierzbicka (1992), for instance, while the words “anger” and “sadness” are culture bound and language specific, semantic primitives such as “‘good’ and ‘bad’ and ‘want’ and ‘happen’” are not. These primitives can describe some of the basic themes that characterize emotion (Johnson-Laird and Oatley, 1989). For example, emotions involve good and bad things that happen to us and to other people, and that we and other people actively do. Emotions also comprise others’ and our own evaluations of ourselves and our actions, and the relationships that can be constructed on the bases of these evaluations. Using semantic primitives to build emotion concepts seems to provide enough nuance to characterize many different emotions. But, despite its power the semantic primitives approach also has some shortcomings. Although the definitions seem to contain something about the antecedents of and situations for emotions, the “hot” or bodily aspects of the emotion are not contained in the definition. This problem might be addressed by calling a set of basic emotions, such as fear, anger, happiness, sadness, and disgust, themselves, semantic primitives (Johnson-Laird and Oatley, 1989). However, neither use of the semantic primitives approach addresses the way in which semantic primitives are represented and processed. Although the assumption must be that the primitives are innate, it is still not clear what is being used when they are activated.

Although it focuses on conceptual structure and differences between emotions, the prototype approach to emotion concepts does not solve these problems either. In the prototype approach (Rosch, 1973), emotion concepts are hierarchically organized and fuzzy, such that boundaries between related categories are not strict. Emotion concepts refer to events described in terms of temporally structured prototypes or scripts that comprise components of emotions, such as antecedents, situations, and bodily characteristics (Russell, 1991). Such elements of the prototypes are probabilistic and not all-or-none in nature. One element, such as a facial expression or a behavior, can be classified as an instance of a particular emotion and these classifications reveal graded structure.

The semantic network model of emotion (Bower, 1981, 1991; Lang, 1984) is the only representational model of emotion concepts proposed in the literature to date. In this approach, knowledge about emotion is represented in a network of units of representations called “nodes.” Basic emotions are conceptualized as central organizing nodes. Units that represent beliefs, antecedents, and physiological patterns associated with a given emotion are linked to the central nodes by connecting pathways. When an emotion unit is activated above some threshold, activation spreads throughout the network to associated information. Autonomic reactions, expressive behaviors, emotion-related events, and personal memories are thereby excited and may enter consciousness. For instance, when one is feeling happy the material in memory

related to happiness becomes activated. As a consequence, one may experience an increase in heart rate and in blood pressure, an activation of the zygomaticus major muscle, and a heightened accessibility to the words and memories associated with happiness. The semantic network model generates hypotheses regarding the structure and content of emotion concepts (Niedenthal, Setterlund, and Jones, 1994, for discussion); however, it fails as an explanatory account, which the following section will discuss.

All models described above are based on a general view of cognition that assumes that higher-order mental content is *amodal* and abstract in format. Thus, it does not preserve analogical information about the low-level perceptual experience of objects, events, or states. The underlying assumption is that representation and initial sensory experience do not take place in the same system and that information taken from the initial experience needs to be redescribed in mental symbols to represent emotion concepts (Bower, 1981; Johnson-Laird and Oatley, 1989; Ortony *et al.*, 1987). Yet, an accumulating body of evidence is often more consistent with a view according to which the activation in the body's sensorimotor and affective systems in many cases constitutes the conceptual content itself.

Embodied simulation of emotion

Unlike amodal accounts of emotion concepts, theories of embodied or simulated concepts hold that perception and action are tightly coupled (Barsalou, 1999; Damasio, 1999; Gallese, 2003; Glenberg, 1997; Miellet, Hoogenboom, and Kessler, 2012; Niedenthal *et al.*, 2005; Smith and Semin, 2007). These basic principles are not new and have long roots in the philosophy of Merleau-Ponty and Heidegger, and the psychology of Vygotsky and Piaget (see also Prinz, 2002). By these accounts, the modality-specific states that represent perception, action, and introspection when one experiences a particular object also serve to represent the object later, offline. Emotion concepts then would refer to bodily states situated in the causal context (Barrett, 2006). For example, embodied emotions theorists suggest that the meanings of emotion words are grounded in their associated behaviors, such as facial expressions and gestures (Hietanen and Leppänen, 2008; Niedenthal, 2007). Because an emotional experience involves a complex interplay between the autonomic nervous system, behavior, facial expressions, cognition, and the limbic area of the brain, embodied representations of emotions themselves are distributed across modality-specific regions of the brain.

Behavioral and neuroimaging evidence supports an embodied emotion account of emotion concepts. In the next section we review findings of studies using language to probe emotion concepts. Then we review work on the face and the body. There are both experimental and correlational tests of the basic predictions of the embodiment of emotion concepts. The former rely on strategies for blocking or facilitating the involvement of the body's emotion systems in order to test their causal role in emotion concept use. Correlational studies use behavioral and neuroimaging methods to assess the occurrence of emotion simulation during emotion concept use. We review both types of evidence in order to evaluate the functional role of the sensorimotor and affect systems in executing tasks that rely on emotion concepts, such as the identification or use of emotion nouns, and the recognition or classification of facial or bodily expression of emotion.

Verbal probes to emotion concepts

A number of inventive methods have been used to block emotion processes during emotional language processing. Havas and colleagues (Havas, Glenberg, Gutowski, Lucarelli, and Davidson,

2010) looked at the function of facial activity in the processing of emotion language by taking advantage of the beauty industry's response to ageing: Botox. Botulinum toxin-A (BTX) is a neurotoxin that paralyzes muscles, reducing the appearance of wrinkles caused by preventing the underlying facial muscles from contracting. Havas *et al.* invited women who were about to receive BTX injections in the corrugator supercilii – which furrows the brows and can cause frown lines – to read happy, sad, and angry sentences and answer comprehension questions. Two weeks later, the same women (now wrinkle-free) returned to read more sentences. Results showed that the BTX injections significantly slowed the women's reading speed for angry and sad, but not happy, sentences. Thus, the denervation of facial muscles blocks facial expressions and seems to hinder emotion-specific language processing.

Feroni and Semin (2009) also found that embodied simulation plays a role in non-conscious processing of emotion words. In this study Dutch students were exposed subliminally to either positive or negative verbs (e.g. “to smile”; “to frown”) and then were invited to rate the funniness of cartoons. During the cartoon-rating task, half of the participants held a pen between their lips in order to block facial responding. Subliminally presented positive verbs primed people to rate the cartoons as funnier when compared with exposure to negative verbs. This effect disappeared, however, for participants holding the pen between their lips. It appears that because these participants were unable to use the muscles involved in a smile while holding the pen, no motor resonance occurred in response to the positive subliminal emotion primes. Thus, in this condition the emotion words could not moderate later behavior, namely, the ratings of the funniness of cartoons.

In a recent neuroimaging study, Moseley, Gallace, and Spence (2012) had eighteen participants read emotion-related action words (such as “dread”) while recording their brain activity in an fMRI scanner. The abstract emotion words activated not only limbic regions of the brain, which are involved in the experience of emotions, but also the motor cortex, suggesting that bodily and facial movements play a fundamental role in emotion concept comprehension. This suggests that we learn what it means to feel “angry” by connecting the gestures and facial expressions we see in others labeled as “angry” with how *we* feel when we are making those gestures and expressions. Thus, the meaning of “anger” is inevitably embedded in behaviors and internal states associated with the experience of anger.

Importantly, embodied simulation may not always be necessary, such as when emotion-knowledge tasks can be performed by recourse to lexical associations in memory or when emotional meaning is not central to task completion (Niedenthal, Winkielman, Mondillon, and Vermeulen, 2009). When reactivation of the modality-specific neural states associated with a given emotion is necessary for a task, such as emotion-expression recognition or deeper emotion concept processing, behavioral expressions of the somatic activation may occur. For instance, when activating an internal representation of the emotion “disgust,” the facial muscles involved in the expression of disgust (picture yourself smelling a carton of sour milk) will become slightly active.

Niedenthal and her colleagues (2009) took advantage of this feature of embodied simulation in order to examine when people do and do not rely on embodied representations of emotions. Specifically, they showed participants sixty concrete nouns, half of which were related to an emotion (e.g. “smile,” “vomit,” “torturer”) and half of which were emotionally neutral (e.g. “chair,” “pocket,” “cube”). Participants were randomly assigned either to judge if the nouns were associated with an emotion, or to indicate whether they were written in capital or small letters, while facial muscle activity was assessed with EMG (electromyogram). Results showed that participants who judged association to emotion, but not the way the words were printed, demonstrated emotion-specific activation of facial muscles while processing the emotion nouns.

When judging nouns associated with “joy,” muscles that formed the smile were activated, and judging “anger”- and “disgust”-related nouns was accompanied by the activation of the emotion-specific muscles as well. Niedenthal and colleagues then replicated this study using nouns that refer to emotion states such as “delighted” and “repelled” and more abstract neutral words like “programmed” and found largely the same pattern of results. These two studies provided evidence for the importance of embodying emotion concepts when the meaning of the concepts is needed for the task. However, the findings are correlational in nature.

To test the causal role of embodiment in emotion concept processing Niedenthal and colleagues conducted a third study using a task similar to the previous two studies, except all participants made the emotion-focused judgment and half of the participants held a pen between their lips throughout the experiment. Holding the pen prevents movement of the zygomaticus major, the muscle that pulls your mouth into a smile, as well as of the levator labii superioris, which allows you to curl your upper lip up in an expression of disgust. They predicted that, for emotion words that relate to joy or disgust, participants holding the pen between their lips would not be able to simulate the appropriate emotions. In fact, the pen significantly reduced accuracy in labeling joy- and disgust-related words as emotional or non-emotional, but had no effect on labeling of anger or neutral concepts. Similar findings have been reported in studies using other physiological indicators of emotion, such as skin conductance (e.g. Oosterwijk, Topper, Rotteveel, and Fischer, 2010).

While associative network models of emotion concepts could be altered and in a sense made unconstrained in order to accommodate any component of emotion and the priming of the concept by each of these, the studies just presented seem more consistent with an account by which emotion concepts are the ability to simulate complex emotional experience as needed. A complete account of emotion concepts might indeed be that the parts of an emotional experience that are relevant to a task are peripherally and centrally re-enacted and matched to or reasoned over, and this modality-specific activation is what emotion concept use actually is. This idea is further suggested by recent work on the processing of emotion from the face and body.

Face probes to emotion concepts

Theories of embodied simulation hold that the body’s periphery – especially the face – as well as the brain’s affective and motor areas are used in tasks of recognition and identification of facial expression of emotion (Niedenthal, 2007; Niedenthal, Mermillod, Maringer, and Hess, 2010; Pitcher, Garrido, Walsh, and Duchaine, 2008). In a recent behavioral study Ponari, Conson, D’Amico, Grossi, and Trojano (2012, study 1) found that blocking mimicry on the lower half of perceivers’ faces compromised the recognition of happiness and disgust expressions, while blocking mimicry on the upper half of perceivers’ faces compromised the recognition of anger expressions. Both manipulations decreased the recognition of fear. Neither the recognition of surprise nor that of sadness was affected. These findings support the embodiment hypothesis because they link the use of muscles involved in a facial expression (e.g. Smith, Cottrell, Gosselin, and Schyns, 2005) to its processing. Similar findings were reported by Maringer, Krumhuber, Fischer, and Niedenthal (2011) in a study of the processing of different types of smiles. In that study, half of the experimental participants were able to freely mimic dynamically “true” and “false” smiles, whereas the remaining half held pencils in their mouths such that facial mimicry was functionally blocked. Participants’ task was to rate each smile on a scale of genuineness. Findings revealed that participants in the mimicry condition judged true smiles as more genuine than false smiles, consistent with previous validation studies. However, in the mimicry-blocked

condition, participants' judgments of genuineness did not vary by smile type. Instead, all smiles were rated as equally genuine. This result was consistent with the hypothesis that the ability to mimic smiles is essential for distinguishing among their subtle meanings.

A recent line of study inspired by research on mirror-touch synaesthetes (MTS) also provides evidence in favor of an embodied account of the processing of facial expression. Individuals with MTS report the vicarious sensation of touch and show increased activation of sensorimotor cortex when they observe others being touched (Blakemore, Bristow, Bird, Frith, and Ward, 2005). Interestingly, MTS individuals also show better recognition of emotion in others than controls (Banissy, Walsch, and Muggleton, 2011). The extant research on MTS led Maister, Tsiakkas, and Tsakiris (2013) to predict that when somatosensory resonance between the bodies of self and other is enhanced, emotional expression recognition is facilitated. They used a procedure for inducing resonance in which a participant sees the face of an unfamiliar other being stroked on the cheek with a cotton swab. If the participant experiences simultaneous strokes of a swab on their own cheek, they experience a type of self-other blurring called the "enfacement illusion." This simultaneous visuotactile experience causes individuals to perceive another's face as more similar to theirs, as indicated by several different tasks (Paladino, Mazzurega, Pavani, and Schubert, 2010). Thus the enfacement illusion seems to lead individuals to incorporate features of the other into their self-concepts. To test the hypothesis that the enfacement illusion increases interpersonal somatosensory resonance, and thereby increases emotion recognition, Maister and colleagues (Maister, Tsiakkas, and Tsakiris, 2013) measured emotion recognition before and after a period of synchronous (versus asynchronous versus control) visuotactile stimulation. On each trial of the emotion recognition task an emotional expression (fear, happiness, or disgust) manifest at one of seven intensity levels was presented and participants categorized the expression as representing one of the three categories. Prior synchronous visuotactile stimulation significantly enhanced recognition of fear (although not the other expressions) at all levels of intensity.

Studies using methods of transcranial magnetic stimulation (TMS) have also supported an embodied account of emotion concepts. TMS can be used to temporarily inhibit the use of a targeted brain region in order to identify its role in a mental process. To the extent that a process is compromised when TMS has been directed at a particular region, that location can be inferred to support that process. The results of several studies implicate somatosensory cortices in the accurate identification of facial expressions (Pitcher *et al.*, 2008; Pourtois *et al.*, 2004). Because the somatosensory system comprises the receptors and processing centers for the sense modalities, including proprioception from the face, this suggests that the body's perceptual experience, and not only visual input, contributes to processing emotion from the face.

Body probes to emotion concepts

The face can certainly communicate a large amount of complex emotion, but disembodied expressive heads are very unusual. Heads are attached to expressive bodies that gesticulate, cower in fear, stand proudly, and gloomily shuffle their feet. There is ample evidence for the role of bodily sensation in emotions (see Kreibitz, 2010) and any complete emotion processing theory should take the role of body into account. Evidence suggests that facial expressions and body postures are processed holistically – that is, perceiving congruent emotion expressions of the face and body facilitates emotion recognition, while incongruency (such as a happy face on an angry body) hinders it (Aviezer, Trope, and Todorov, 2012a; Meeren, van Heijnsbergen, and De Gelder, 2005).

A series of studies showed that emoting bodies influence the perceived emotions of ambiguous faces and voices (Van den Stock, Righart, and De Gelder, 2007). Flack, Laird, and Cavallaro (1999) manipulated people's facial and bodily emotion expressions by giving them precise directions without naming specific emotions: for instance, for a smile, they instructed participants to push the corners of their mouths up and back. After each position, participants completed mood measures. Both facial and bodily feedback influenced the participants' moods, and emotion ratings were most intense when the emotions of the face and body were congruent.

Bodily expressions may sometimes do more than simply supplement the information provided by the face. Aviezer, Trope, and Todorov (2012b) showed that some expressions, such as anger and joy, become difficult to discriminate at their "peak intensities," because they all resemble a wide-mouthed scream. Thus, the body – slumped in sadness or standing triumphantly tall – provides perceivers with better information about the person's emotion. Other studies demonstrate that people can reliably infer emotion from others' gait patterns (Karg, Kühnlenz, and Buss, 2010; Michalak *et al.*, 2009), movement during dialogue (Clarke, Bradshaw, Field, Hampson, and Rose, 2005), dynamic and static postures (Atkinson, Dittrich, Gemmell, and Young, 2004), and movement to music (Burger, Saarikallio, Luck, Thompson, and Toiviainen, 2012). While it may be unsurprising that the body provides affective information, less clear is how others process this information.

Insight into this question comes from human and non-human research into "mirror neurons," which become active both during the completion of a particular action and during the observation of somebody else performing that action (Rizzolatti, Fogassi, and Gallese, 2001). If our brains simulate bodily actions of others, it is logical to assume that this applies to emotional bodily actions. Indeed, an fMRI study by Grèzes, Pichon, and de Gelder (2007) showed that areas involved in action representation activated more when participants observed fearful, as opposed to neutral, dynamic bodies. This difference might be due to the unique importance of emotional movements: it is highly adaptive to quickly react to the fearful displays of others, so the brain may simulate such emotional actions more than neutral actions. Importantly, Oosterwijk, Rotteveel, Fischer, and Hess (2009) found that generating words related to pride or disappointment alters how upright people sit in their chairs, suggesting that using emotion knowledge changes the bodily emotion expression. Such findings suggest that mirror neurons and action representations facilitate the processing of emotional information. Making that claim, however, requires experimental manipulation; therefore, Stepper and Strack (1993) administered a bogus achievement test to male participants positioned into slumped or upright postures. All participants were informed that they performed "far above the average" on the tests and then completed a mood questionnaire. The slumped participants reported feeling significantly less proud than the upright or control participants, but only if they were moved into the position directly before receiving feedback on their achievement tests. This provided preliminary evidence that bodily feedback while in a slumped posture reduces feelings of pride. Interestingly, an inverse relationship was observed for women (Roberts and Arefi-Afshar, 2007). This finding may be due to gender differences in social dominance. Women, who typically experience less social dominance than men, may be less able to recognize the proprioceptive feedback involved in a proud, upright posture. While the moderation by gender complicates the story, it does not discount an embodied simulation explanation. Still, the extent to which action representation of body movements aids in the recognition of others' emotional states remains unclear.

The theory and evidence summarized above suggest that mimicking another's gestures and postures may facilitate understanding of their emotional states. This suggests that embodied states are more than merely reflexive or associated responses. Rather, they may constitute the core of conceptual knowledge about emotion.

Conclusions

The present chapter reviewed evidence that when probed with language and facial and bodily expressions of emotion, emotion concepts seem to be embodied. Behavioral and neuroimaging results are consistent with the view that emotion concepts can be viewed as involving the capacity for emotional re-enactment. The findings are also consistent with a view of emotion as a complex, loosely coordinated experience involving the autonomic nervous system, behavior, facial expressions, cognition, and the limbic areas of the brain. As such, embodied representations of emotions are distributed across modality-specific regions of the brain. A probe to one of these systems may generate simulation in others, as needed for the task.

It is important to note that embodied theories are evolving theories. There is strong evidence for the involvement of motor and somatosensory cortices and peripheral body parts in the processing of emotional information, but it is time to move from binary questions (such as whether embodiment is causal to information processing or not) to more precise statements about how and when the body's central sensorimotor, affective, and peripheral mechanisms are necessarily involved. In addition, important components of the theories require more precise definition. For instance, while facial mimicry seems to be important for identification of facial expression in some cases, both the definition of mimicry and its measurement in real time await substantial progress.

A growing body of evidence suggests that the body's reproduction of parts of an emotional experience constitute conceptual content for emotion. The words "disgust" and "interest" are not mentally grounded by disembodied symbols but are grounded by parts of the bodily state that are re-enacted to support perception and thought.

References

- Atkinson, A. P., Dittrich, W. H., Gemmell, A. J., and Young, A. W. (2004). Emotion perception from dynamic and static body expressions in point-light and full-light displays. *Perception*, 33, 717–746.
- Aviezer, H., Trope, Y., and Todorov, A. (2012a). Holistic person processing: Faces with bodies tell the whole story. *Journal of Personality and Social Psychology*, 103(1), 20–37.
- (2012b). Body cues, not facial expressions, discriminate between intense positive and negative emotions. *Science*, 338(6111), 1225–29.
- Banissy, M. J., Walsh, V., and Muggleton, N. G. (2011). Mirror-touch synaesthesia: A case of faulty self-modelling and insula abnormality. *Cognitive Neuroscience*, 2(2), 114–15.
- Barrett, L. F. (2006). Are emotions natural kinds? *Perspectives on Psychological Science*, 1(1), 28–58.
- Barrett, L. F., and Russell, J. A. (1999). The structure of current affect controversies and emerging consensus. *Current Directions in Psychological Science*, 8(1), 10–14.
- Barsalou, L. W. (1999) Perceptual symbol systems. *Behavioral and Brain Sciences*, 22(4), 577–660.
- Blakemore, S. J., Bristow, D., Bird, G., Frith, C., and Ward, J. (2005). Somatosensory activations during the observation of touch and a case of vision–touch synaesthesia. *Brain*, 128(7), 1571–83.
- Bower, G. H. (1981). Mood and memory. *American Psychologist*, 36(2), 129–48.
- (1991). Mood congruity of social judgments. *Emotion and social judgments*. Oxford: Pergamon Press.
- Burger, B., Saarikallio, S., Luck, G., Thompson, M. R., and Toiviainen, P. (2012). Emotions move us: Basic emotions in music influence people's movement to music. In E. Cambouropoulos, C. Tsourgas, P. Mavromatis, and C. Pasiadis (Eds.), *Proceedings of the 12th International Conference on Music Perception and Cognition (ICMPC) and 8th Triennial Conference of the European Society for the Cognitive Sciences of Music (ESCOM)*. European Society for the Cognitive Sciences of Music website. Retrieved from http://icmpe-escom2012.web.auth.gr/sites/default/files/papers/177_Proc.pdf
- Clarke, T. J., Bradshaw, M. F., Field, D. T., Hampson, S. E., and Rose, D. (2005). The perception of emotion from body movement in point-light displays of interpersonal dialogue. *Perception*, 34(10), 1171–80.
- Damasio, A. R. (1999). *The feeling of what happens: Body and emotion in the making of consciousness*. New York: Harcourt.

- Flack, W. F., Laird, J. D., and Cavallaro, L. A. (1999). Separate and combined effects of facial expressions and bodily postures on emotional feelings. *European Journal of Social Psychology*, 29(2), 203–17.
- Foroni, F., and Semin, G. R. (2009). Language that puts you in touch with your bodily feelings: The multimodal responsiveness of affective expressions. *Psychological Science*, 20(8), 974–80.
- Gallese, V. (2003). The shared manifold nature of interpersonal relations: The quest for a common mechanism. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 358(1431), 517–28.
- Glenberg, A. M. (1997). What memory is for: Creating meaning in the service of action. *Behavioral and Brain Sciences*, 20(1), 41–50.
- Grèzes, J., Pichon, S., and de Gelder, B. (2007). Perceiving fear in dynamic body expressions. *NeuroImage*, 35(2), 959–67.
- Havas, D. A., Glenberg, A. M., Gutowski, K. A., Lucarelli, M. J., and Davidson, R. J. (2010). Cosmetic use of botulinum toxin-A affects processing of emotional language. *Psychological Science*, 21(7), 895–900.
- Hietanen, J. K., and Leppänen, J. M. (2008). Judgment of other people's facial expressions of emotions is influenced by their concurrent affective hand movements. *Scandinavian Journal of Psychology*, 49(3), 221–30.
- Johnson-Laird, P. N., and Oatley, K. (1989). The language of emotions: Analysis of a semantic field. *Cognition and Emotion*, 3(2), 81–123.
- Karg, M., Kühnlenz, K., and Buss, M. (2010). Recognition of affect based on gait patterns. *IEEE Transactions on Systems, Man, and Cybernetics B: Cybernetics*, 40(4), 1050–61.
- Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological Psychology*, 84(3), 394–421.
- Lang, P. J. (1984). Cognition in emotion: Cognition in action. In C. E. Izard, J. Kagan, and R. B. Zajonc (Eds.), *Emotions, cognition, and behavior*. New York: Cambridge University Press.
- Lang, P. J., Bradley, M. M., and Cuthbert, B. N. (1990). Emotion, attention, and the startle reflex. *Psychological Review*, 97(3), 377–95.
- Maister, L., Tsiakkas, E., and Tsakiris, M. (2013). I Feel your fear: Shared touch between faces facilitates recognition of fearful facial expressions. *Emotion*, 13(1), 7–13.
- Maringer, M., Krumhuber, E. G., Fischer, A. H., and Niedenthal, P. M. (2011). Beyond smile dynamics: Mimicry and beliefs in judgments of smiles. *Emotion*, 11(1), 181–87.
- Mayer, J. D. and Gaschke, Y. N. (1988). The experience and meta-experience of mood. *Journal of Personality and Social Psychology*, 55(1), 102–11.
- Meeren, H. K., van Heijnsbergen, C. C., and De Gelder, B. (2005). Rapid perceptual integration of facial expression and emotional body language. *Proceedings of the National Academy of Sciences of the United States of America*, 102(45), 16518–23.
- Michalak, J., Troje, N. F., Fischer, J., Vollmar, P., Heidenreich, T., and Schulte, D. (2009). Embodiment of sadness and depression – Gait patterns associated with dysphoric mood. *Psychosomatic Medicine*, 71(5), 580–87.
- Mielliet, S., Hoogenboom, N., and Kessler, K. (2012). Visual and embodied perception of others: The neural correlates of the “Body Gestalt” effect. *Journal of Vision*, 12(9), 824.
- Moseley, G. L., Gallace, A., and Spence, C. (2012). Bodily illusions in health and disease: Physiological and clinical perspectives and the concept of a cortical “body matrix.” *Neuroscience & Biobehavioral Reviews*, 36(1), 34–46.
- Niedenthal, P. M. (2007). Embodying emotion. *Science*, 316(5827), 1002–5.
- (2008). Emotion concepts. In M. Lewis, J. M. Haviland-Jones, and L. F. Barrett (Eds.), *Handbook of emotion* (3rd ed.). New York: Guilford.
- Niedenthal, P. M., Barsalou, L. W., Winkielman, P., Krauth-Gruber, S., and Ric, F. (2005). Embodiment in attitudes, social perception, and emotion. *Personality and Social Psychology Review*, 9(3), 184–211.
- Niedenthal, P. M., Mermillod, M., Maringer, M., and Hess, U. (2010). The simulation of smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *Behavioral and Brain Sciences*, 33(6), 417–33.
- Niedenthal, P. M., Setterlund, M. B., and Jones, D. E. (1994). Emotional organization of perceptual memory. In P. M. Niedenthal and S. Kitayama (Eds.), *The heart's eye: Emotional influences in perception and attention* (pp. 87–113). San Diego, CA: Academic Press.
- Niedenthal, P. M., Winkielman, P., Mondillon, L., and Vermeulen, N. (2009). Embodiment of emotion concepts. *Journal of Personality and Social Psychology*, 96(6), 1120–36.
- Oosterwijk, S., Rotteveel, M., Fischer, A. H., and Hess, U. (2009). Embodied emotion concepts: How generating words about pride and disappointment influences posture. *European Journal of Social Psychology*, 39(3), 457–66.

- Oosterwijk, S., Topper, M., Rotteveel, M., and Fischer, A. H. (2010). When the mind forms fear: Embodied fear knowledge potentiates bodily reactions to fearful stimuli. *Social Psychological and Personality Science*, 1(1), 65–72.
- Ortony, A., Clore, G. L., and Foss, M. A. (1987). The referential structure of the affective lexicon. *Cognitive Science*, 11(3), 341–64.
- Paladino, M., Mazzurega, M., Pavani, F., and Schubert, T. W. (2010). Synchronous multisensory stimulation blurs self-other boundaries. *Psychological Science*, 21(9), 1202–7.
- Pitcher, D., Garrido, L., Walsh, V., and Duchaine, B. C. (2008). Transcranial magnetic stimulation disrupts the perception and embodiment of facial expressions. *Journal of Neuroscience*, 28(36), 8929–33.
- Ponari, M., Conson, M., D’Amico, N. P., Grossi, D., and Trojano, L. (2012). Mapping correspondence between facial mimicry and emotion recognition in healthy subjects. *Emotion*, 12(6), 1398–1403.
- Pourtois, G., Sander, D., Andres, M., Grandjean, D., Reveret, L., Olivier, E., and Vuilleumier, P. (2004). Dissociable roles of the human somatosensory and superior temporal cortices for processing social face signals. *European Journal of Neuroscience*, 20(12), 3507–15.
- Prinz, J. J. (2002). Consciousness, computation, and emotion. In S. C. Moore and M. Oaksford (Eds.), *Emotional cognition: From brain to behaviour*. Amsterdam: John Benjamins.
- Reisenzein, R. (1994). Pleasure-arousal theory and the intensity of emotions. *Journal of Personality and Social Psychology*, 67(3), 525–39.
- Rizzolatti, G., Fogassi, L., and Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience*, 2(9), 661–70.
- Roberts, T.-A., and Arefi-Afshar, Y. (2007). Not all who stand tall are proud: Gender differences in the proprioceptive effects of upright posture. *Cognition and Emotion*, 21(4), 714–27.
- Rosch, E. H. (1973). Natural categories. *Cognitive Psychology*, 4(3), 328–50.
- Russell, J. A. (1991). In defense of a prototype approach to emotion concepts. *Journal of Personality and Social Psychology*, 60(1), 37–47.
- Russell, J. A., and Barrett, L. F. (1999). Core affect, prototypical emotional episodes, and other things called emotion: Dissecting the elephant. *Journal of Personality and Social Psychology*, 76(5), 805–19.
- Russell, J. A., Lewicka, M., and Nitt, T. (1989). A cross-cultural study of a circumplex model of affect. *Journal of Personality and Social Psychology*, 57(5), 848–56.
- Shaver, P., Schwartz, J., Kirson, D., and O’Connor, C. (1987). Emotion knowledge: Further exploration of a prototype approach. *Journal of Personality and Social Psychology*, 52(6), 1061–86.
- Smith, E. R., and Semin, G. R. (2007). Situated social cognition. *Current Directions in Psychological Science*, 16(3), 132–35.
- Smith, M. L., Cottrell, G. W., Gosselin, F., and Schyns, P. G. (2005). Transmitting and decoding facial expressions. *Psychological Science*, 16(3), 184–89.
- Stepper, S., and Strack, F. (1993). Proprioceptive determinants of emotional and nonemotional feelings. *Journal of Personality and Social Psychology*, 64(2), 211–20.
- Van den Stock, J., Righart, R., and De Gelder, B. (2007). Body expressions influence recognition of emotions in the face and voice. *Emotion*, 7(3), 487–94.
- Wierzbicka, A. (1992). Defining emotion concepts. *Cognitive Science*, 16, 539–81.

EMBODIMENT IN THE CONSTRUCTION OF EMOTION EXPERIENCE AND EMOTION UNDERSTANDING

Suzanne Oosterwijk and Lisa Feldman Barrett

Introduction

Imagine that you are cycling home. Suddenly you are cut off by a right-turning car. You stop. Your hands are gripping the bars of the bicycle. Your heart is banging in your chest.

If this situation happens in real time, you may experience a state of anger or fear. This discrete emotional state emerges from the interplay between sensory information from the world (e.g. what you see, hear, smell, feel), internal information from the body (e.g. a racing heart, tense muscles) and conceptual representations linked to previous experiences that are relevant to the situational context (Barrett, 2012). Now consider that you *observe* this state in someone else, or that someone else *describes* this experience to you, or that you *read* about this experience in a book. How do we construct meaning in these instances of emotion?

In this chapter we argue that understanding instances of emotion in social cognition or language is produced by the same constructive process as the experience of discrete emotions in the individual (Barrett, 2006). We begin our chapter by laying out our constructionist framework for emotion. Then we will discuss how this framework can be applied to emotion understanding. Since our framework formulates specific predictions about how instances of emotion are constructed in the brain, we will pay special attention to findings from the neuroimaging literature.

A constructionist perspective on emotion

Psychological constructionism is an innovative theoretical framework that proposes that instances of the mind are constructed from basic psychological processes. These psychological processes are not specifically and uniquely tied to psychological states, but serve domain-general functions (Lindquist and Barrett, 2012; Barrett, 2012). This framework stands in contrast to faculty psychology perspectives that argue for modular systems in the brain and body that subserve discreteness and specificity (see Barrett, 2006).

Emotions are situated conceptualizations

According to our constructionist framework, the mind is continuously engaged in three basic psychological processes: (1) representing basic sensory information from the world; (2) representing basic sensations from the body; and (3) making meaning of internal and external sensations through the process of conceptualization (Barrett, 2012; Lindquist and Barrett, 2012; Barrett and Satpute, 2013). The way these basic processes combine in the construction of emotion is specified in the conceptual act theory (Barrett, 2006; Wilson-Mendenhall, Barrett, Simmons, and Barsalou, 2011). This model defines instances of emotion as “conceptual acts” in which sensorimotor and interoceptive information (i.e. core affect; see Barrett and Bliss-Moreau, 2009) are integrated with concept knowledge and memories to create rich, embodied, situated conceptualizations (Barrett, 2006, 2012).

The term situated conceptualization was first introduced to explain how categories (e.g. bicycles, cats) are represented in the mind (Barsalou, 1999). Since then, this principle has been applied to explain perception, (social) cognition, memory and language (see Barsalou, 2009) and the subjective quality of emotions and other mental states (see Wilson-Mendenhall *et al.*, 2011). According to the conceptual act theory, individuals will experience different emotions depending on the relative weighting of domain-general processes in each unique situated conceptualization. For example, when a person is almost hit by a car, interoceptive information (e.g. change in heart rate) and exteroceptive information (e.g. the visual percept of a car that is too close) may be integrated with knowledge representations (e.g. knowing that you had right of way) to create a situated conceptualization of anger. Alternatively, the same sensations could be weighted differently and integrated with different knowledge representations (e.g. predictions about what would have happened if you had been hit) to create a situated conceptualization of fear (see for a detailed discussion Wilson-Mendenhall *et al.*, 2011). In both examples the resulting emotion is an emergent phenomenon, in that its constituents cannot be subjectively identified once the emotion is manifested in subjective consciousness (see Barrett, 2012).

Since situated conceptualizations are tied to the situational context at hand, our view explicitly predicts that instances of emotion are heterogeneous and show variability both between and within superordinate categories. In other words, we argue that different situated conceptualizations underlie instances of *different* emotions (e.g. anger vs. fear after being almost hit by a car) and instances of the *same* emotion (e.g. anger in a stadium vs. anger at work). Moreover, a basic premise of our constructionist framework is that all emotional states are intrinsically embodied, because sensorimotor and interoceptive states are among the basic building blocks of emotion (Barrett and Lindquist, 2008, Barrett and Bliss-Moreau, 2009; see for similar views Damasio, 2000; Craig, 2009; Critchley, Wiens, Rotshtein, Ohman, and Dolan, 2004).

A constructionist functional architecture of the brain

A basic assumption of our constructionist framework is that the domain-general processes that form the basic building blocks of all instances of emotion are supported by large-scale distributed networks in the brain (see Lindquist, Wager, Kober, Bliss-Moreau, and Barrett, 2012; Oosterwijk, Lindquist, *et al.*, 2012; Lindquist and Barrett, 2012; Barrett and Satpute, 2013). These networks include the limbic network that supports the brain’s ability to generate and/or represent homeostatic and visceral changes (see Lindquist and Barrett, 2012; Oosterwijk, Lindquist, *et al.* 2012), the somatomotor network that represents and generates exteroceptive and proprioceptive sensations (Yeo *et al.*, 2011), the salience network (Seeley, *et al.*, 2007) and the mentalizing network. In the interest of space we will only discuss the salience network and the mentalizing

network in more detail (see for a description of the other networks, Oosterwijk, Lindquist, *et al.* 2012; Barrett and Satpute, 2013).

We hypothesize that the domain-general process of representing and generating internal sensations from the body is supported by the salience network (and the limbic network). More specifically, we hypothesize that the salience network, including the dorsal anterior cingulate cortex and the anterior insula, supports the brain's ability to use homeostatic and visceral information to guide attention and motor behavior and to re-represent this information in subjective consciousness (see Oosterwijk, Lindquist, *et al.*, 2012; Barrett and Satpute, 2013). This proposed function of the salience network is consistent with its general role in interoception (e.g. Critchley *et al.*, 2004) and its common involvement in emotion perception and experience (Kober *et al.*, 2008; Lindquist *et al.*, 2012). This general role is further supported by the finding that voxels associated with distinct emotions in fact converge within the salience network (Touroutoglou, Lindquist, Hollenbeck, Dickerson, and Barrett, under review). Moreover, functional neuroimaging studies demonstrate that the salience network engages when people generate emotions in the scanner (Oosterwijk, Lindquist, *et al.*, 2012) and that the anterior insula – an important node in the salience network – is active both when people perform an interoceptive task and when they subjectively rate their emotions (Zaki, Davis, and Ochsner, 2012).

In our framework, sensorimotor and interoceptive states are made meaningful through the process of conceptualization. We hypothesize that this domain-general process is supported by the mentalizing network (Barrett and Satpute, 2013; Lindquist and Barrett, 2012; Lindquist *et al.*, 2012) also widely known as the default network (e.g. Buckner, Andrews-Hanna, and Schacter, 2008). This network includes the medial prefrontal cortex, posterior cingulate cortex, precuneus, medial temporal lobe and the superior temporal sulcus. In particular, we argue that this network integrates sensorimotor and interoceptive information with concept knowledge, language and memory representations, to produce rich situated conceptualizations. This hypothesized role of the mentalizing network is supported by several meta-analyses that show consistent activation of this network during emotional experience (Kober *et al.*, 2008; Lindquist *et al.*, 2012). Furthermore, nodes in this network engage when people regulate their emotions (Wager, Davidson, Hughes, Lindquist, and Ochsner, 2008), when people perform tasks that involve the generation of affective meaning (Roy, Shohamy, and Wager, 2012) and when people subjectively rate valence and arousal (Wilson-Mendenhall, Barrett, and Barsalou, 2013). The mentalizing network may be divided into a dorsal and a ventral subnetwork that supports slightly different functions (Barrett and Satpute, 2013). The dorsal part may be relatively more involved in situated conceptualizations from a “third-person” perspective, in which reflections, judgments or “metacognition” plays an important role (see also Andrews-Hanna, Reidler, Sepulcre, Poulin, and Buckner, 2010). The ventral part may be relatively more involved in situated conceptualizations from a “first-person” perspective, in which feeling states are generated in the self, or reused to understand the experience of another person. In this latter case, instances of emotion may involve an interaction between the salience network that generates affective states and the ventral parts of the mentalizing network to integrate the embodied information (Lombardo *et al.*, 2009). Importantly, the mentalizing network plays a role in emotion, but also in other instances of the mind, including self-relevant thought (e.g. Northoff *et al.*, 2006), internal mentation (Andrews-Hanna *et al.*, 2010), autobiographical memory and social cognition (Spreng and Grady, 2010). We argue that what unifies these different psychological domains is the general role of the mentalizing network in generating meaningful representations of internal and external sensations that are tied to the particular situational context.

The basic role of context

The principle of situated conceptualization implies that instances of emotion cannot be understood separately from the context in which they occur (Barrett, 2012). First, people may experience different emotions depending on the current state of their body (e.g. being tired or hungry) or the auditory, visual or tactile information present in a situation. Second, different contexts evoke different representations of previous experience, different situational predictions, different categorizations and different regulation rules. As a result, each unique instance of an emotion category is tied to the situation at hand, so that an emotion category reflects a population of situated instances with meaningful variability. This variability may be reflected in subjective experience, bodily changes, expression or action. For example, guided by regulation rules, anger in a stadium may include large movements, vocalizations and facial expressions, whereas anger at work may lack this outward behavior. It is important to note that, within our model, sensorimotor and interoceptive states are regulated as part of the constructive process and not “after the fact.” Although regulation may occur after an emotional state is represented in subjective consciousness, regulation often occurs *during* the formation of a situated conceptualization (Gross and Barrett, 2011). Since emotions are emergent states, people cannot report on these regulatory processes, nor are any of the other domain-general processes available to consciousness (Barrett, 2012).

The impact of context in the construction of emotion is well illustrated by two functional neuroimaging studies performed in our lab. Wilson-Mendenhall and colleagues (2011) examined the neural systems that engaged when people conceptualized situations describing physical danger (e.g. being lost in the woods) or social evaluation (e.g. being unprepared during a meeting at work) as instances of anger or fear. Consistent with our framework, anger and fear demonstrated different patterns of activation depending on the situational context. For example, physical danger situations engaged the salience network more than social evaluation situations. Another study from our lab further demonstrated that networks in the brain engaged with different strengths depending on how people conceptualized a negative situation (Oosterwijk, Lindquist, *et al.*, 2012). The salience network was relatively more strongly engaged when people experienced a negative situation as a bodily feeling (e.g. rise in heart rate) or an emotion (e.g. fear), whereas the mentalizing network was relatively more strongly engaged when people generated a thought about the situation. This work suggests that domain-general processes can be more or less relevant depending on the way people represent a situation in their minds.

So far we have argued that large-scale networks in the brain, that support domain-general processes, interact to produce emotional experience in the individual. The different contributions of these processes are guided by context, resulting in great individual and situational variability across instances of emotional experience. In the next section, we argue that this framework can also be applied to instances of emotion understanding.

A constructionist view on emotion understanding

If sensorimotor and interoceptive sensations are a constituent of subjective emotional experience, then these states may also play an important role in representing emotion in perception (e.g. perceiving fear in someone else), cognition (e.g. thinking about your partner’s anger), memory (e.g. retrieving a happy memory) and language (e.g. reading about a disgusting experience). This prediction resonates with embodied simulation theories that propose that observing actions, feelings and emotions in other people engages the same neural circuits as experiencing actions, sensations and emotions in the self (e.g. Gallese, Keysers, and Rizzolatti, 2004; Bastiaansen, Thoux, and Keysers, 2009). Furthermore, it is consistent with views that propose that the

conceptual system for emotion is grounded in sensorimotor and bodily states associated with emotions (Barsalou, 1999; Niedenthal, 2007; Barrett, 2006). According to these views, multi-modal systems in the brain and body *simulate* experiential states in order to represent online instances of emotion (e.g. observing someone who is frightened) and offline instances of emotion (e.g. reading about a frightening event), even in the absence of direct sensory or bodily stimulation.

The core of our constructionist framework is that emotion understanding is generated by situated conceptualizations that integrate simulations across large-scale distributed networks in the brain that support domain-general processes (see also Barrett and Satpute, 2013). Although the term “embodied cognition” may specifically refer to simulations that have a “bodily format” (Gallese and Sinigaglia, 2011), we argue that situated conceptualizations integrate both sensorimotor and interoceptive simulations *and* simulations of introspections (see also Barsalou, 2009). Other approaches also maintain a definition of simulation that includes bodily, sensory and affective resonance (e.g. taking over the visceral state of someone else) *and* mentalizing (e.g. taking over the mental content of someone else) (Zaki and Ochsner, 2012; Decety, 2011; Keysers and Gazzola, 2007; Waytz and Mitchell, 2011).

Although we propose that sensorimotor and interoceptive states are constituents of emotion understanding, we argue against a fixed one-to-one correspondence between bodily states and discrete emotions (see Barrett, 2006; Lindquist and Barrett, 2012). Instead, most relationships between sensorimotor and interoceptive states and discrete emotional experience exist by association. Even though the brain contains circuitry for basic behavioral adaptations like freezing, fleeing and fighting, these adaptations are neither necessary nor sufficient for emotion (e.g. Barrett, 2012; LeDoux, 2012). People don’t routinely freeze, flee or fight in emotion, and when they do, it is not always in the way prescribed by emotion stereotypes (e.g. people can withdraw during anger or fight during fear). When the brain predicts that one of these behavioral adaptations might be necessary, this produces sensorimotor and interoceptive changes (Barrett and Bar, 2009) which are experienced as a state of pleasure or displeasure with some degree of arousal (i.e. a core affective state; see Barrett and Bliss-Moreau, 2009). Importantly, these sensorimotor and interoceptive changes can *contribute* to emotion understanding as part of a situated conceptualization, but these changes do not *causally evoke* discrete emotional meaning without conceptualization (e.g. a rise in heart rate may indicate fear, but also sexual arousal or interest). In other words, similar forms of emotion understanding emerge because people share situated conceptualizations and not because they share hard-wired “emotion mechanisms” (Barrett, 2006).

The situated conceptualizations that people share are produced by learning, cultural transfer, and commonalities in personal experiences (Barrett, 2006, 2013; Barrett, Wilson-Mendenhall, and Barsalou, in press). To give a specific example, if people learn that a slumped posture is an expression of disappointment – because they encounter events that are labeled as disappointment and include this expression – then this postural state may become part of a situated conceptualization for disappointment (Barsalou, 1999). Consequently, when people retrieve emotion knowledge about disappointment, for instance when they think about failure, the situated conceptualization may produce a slumped body posture (see Oosterwijk, Rotteveel, Fischer, and Hess, 2009). Nevertheless, even though situated conceptualizations are likely shared, people can still use different situated conceptualizations within their personal “repertoire” to understand instances of emotion across different contexts (see also Hess and Fischer, 2013).

The construction of emotion understanding

A large body of research demonstrates that understanding emotions across different tasks is accompanied by sensorimotor, interoceptive and introspective simulation (see for an overview

Winkielman, Niedenthal, and Oberman, 2008). Behavioral research involving physiological measures demonstrates that the observation of affective states or the experience of empathy is accompanied by changes in the internal state of the body (e.g. Levenson and Ruef, 1992; Cwir, Carr, Walton, and Spencer, 2011). Research focusing on facial muscle activation demonstrates spontaneous movements in the face when people perceive emotional expressions in others (e.g. Dimberg, 1990; Hess and Blairy, 2001). Simulation effects have also been shown in tasks where people do not see or hear others directly, such as when processing emotion language (e.g. Havas, Glenberg, and Rinck, 2007; Oosterwijk, Winkielman, *et al.*, 2012). Moreover, multiple studies demonstrate that processing emotion in conceptual tasks is accompanied by spontaneous changes in the body, including changes in the sympathetic nervous system (Vrana and Rollock, 2002; Oosterwijk, Topper, Rotteveel, and Fischer, 2010), facial muscles (Niedenthal, Winkielman, Mondillon, and Vermeulen, 2009) and posture (Oosterwijk *et al.*, 2009).

Neuroimaging experiments further support the idea of simulation in emotion understanding. For example, several neuroimaging experiments demonstrate neural overlap when people experience, imagine and observe disgust (Jabbi, Bastiaansen, and Keysers, 2008; Wicker *et al.*, 2003). Furthermore, emotional empathy commonly activates regions within the salience network, the somatomotor network and the mentalizing network that also engage during emotional experience in the self (e.g. Fan, Duncan, De Greck, and Northoff, 2010; Decety, 2011; Zaki, Weber, Bolger, and Ochsner, 2009). Finally, there is an abundance of findings in the social neuroscience literature that demonstrates that the mentalizing network is involved when people make attributions about the content of other people's mental state (e.g. Amodio and Frith, 2006; Van Overwalle and Baetens, 2009).

Another field of research that supports simulation accounts of emotion understanding focuses on emotion language. Research has shown, for instance, that regions in the salience network and the somatomotor network are active when people process concrete and abstract emotion words (Mosely, Carota, Hauk, Mohr, and Pulvermüller, 2012). A neuroimaging study that compared self- and other-linked emotion words found activation patterns in the salience network for both categories, whereas the mentalizing network was only active for self-linked emotion words (Herbert, Herbert, and Pauli, 2011). Another interesting study demonstrated that engagement of the salience network when processing emotional narratives was correlated with affective word use when people describe their feelings (Saxbe, Yang, Borofsky, and Immordino-Yang, 2013). Together, these studies show that systems supporting the generation and representation of sensorimotor, interoceptive and introspective states engage when people process emotion language. A recent study by Oosterwijk, Mackey, Wilson-Mendenhall, Winkielman, and Paulus (submitted) explicitly tested whether the situational context directed these different forms of simulation (see also Oosterwijk, Winkielman, *et al.*, 2012). Participants processed sentences describing emotional (e.g. fear, joy) and non-emotional states (e.g. hunger, thinking) from an internal (i.e. focusing on feelings and introspection) or external perspective (i.e. focusing on expression and action). Consistent with our proposal that emotions are represented in a situated fashion, we found that internal emotion sentences were associated with more engagement of the mentalizing network, whereas external sentences overall were associated with more engagement of regions associated with action representation. This work is consistent with recent calls in the literature that argue for contextual flexibility in simulation during language processing (Willems and Casasanto, 2011).

The latter study is a good example of how different contexts involve different patterns of simulation. Based on this work, and guided by the principle of situated conceptualization, we generally predict that in situations where perceptual cues about a person's bodily state or actions are a dominant source of information, simulations of actions and sensory states may be most

relevant for understanding (see also Van Overwalle and Baetens, 2009). This would involve a stronger engagement of the dorsal attention and somatomotor network that supports the generation and representation of exteroceptive sensations (see Barrett and Satpute, 2013; Oosterwijk, Lindquist, *et al.*, 2012). In situations where the internal state of a person is a dominant source of information, as in pain or disgust, we predict that interoceptive simulations, sometimes called “affective mirroring,” may be most relevant for understanding. This would involve a relatively stronger engagement of the salience network. And finally, when introspections, intentions, goals or discrete feelings are most relevant for understanding, or when the state of a person has to be deduced from contextual information (see Zaki, Hennigan, Weber, and Ochsner, 2010), we predict a relatively stronger engagement of the mentalizing network (see for similar views Zaki and Ochsner, 2012; Van Overwalle and Baetens, 2009). This contextualist view on simulation is supported by a recent meta-analysis on pain that found that viewing pictures of body parts in painful situations engaged somatosensory cortices and regions associated with action understanding, whereas viewing abstract information in which the presence of pain could only be inferred from a cue engaged the mentalizing system (Lamm, Decety, and Singer, 2011). Different patterns of simulation were also observed in a study that manipulated processing goals (e.g. *how* is she showing her feelings vs. *why* is she feeling them) when people viewed emotional episodes in others (Spunt and Lieberman, 2011).

Together, the data reviewed above clearly support the idea that dynamic, multimodal simulations underlie the understanding of emotion. These simulations occur in the neural networks that also produce subjective emotional experiences in the individual. Our constructionist framework thus connects a range of emotional phenomena by proposing that emotional experience and understanding share a constructive process that dynamically adapts to the context at hand.

Future directions

Although some progress has been made in answering questions about how the complexity of emotion is grounded in the brain, body and situational context, there are still many questions that call for further investigation. Since this chapter is specifically focused on the topic of embodiment, we will propose a few avenues for future research that specifically highlight embodied simulation processes in emotion understanding.

First of all, we believe that research aimed at understanding instances of emotion should more often explore the role of context. Within this question it is important to examine how simulation adapts dynamically to the demands of the external situation, and to the internal context of the observer, including goals and motivations (see also Hess and Fischer, 2013). Second, little attention has been given in embodiment research to individual differences (Meier, Schnall, Schwarz, and Bargh, 2012). It is possible, however, that individual differences may result in heterogeneous situated conceptualizations. For example, internal sensations may be weighed differently in situated conceptualizations in individuals with high (or low) interoceptive sensitivity. As a result, differences in interoceptive sensitivity may not only lead to different emotional experiences (Herbert and Pollatos, 2012) but also to different patterns of simulation when understanding emotion in others. Third, we know very little about how cultural differences impact embodied simulation, even though people from different cultures differ in emotional expression and experience (e.g. Boiger and Mesquita, 2012; Jack, Garrod, Yu, Caldara, and Schyns, 2012). An interesting hypothesis that follows from this heterogeneity is that mismatches may occur between simulations in the observer and the actual state of the observed other when people have different cultural backgrounds.

In closing, we believe that models of emotion need to explain both similarity and variation in instances of emotion. Our proposal that instances of emotion are produced by situated conceptualizations may contribute to the endeavor to explain emotion in all its complexity. Yet, even though each instance of emotion is most likely reflected by a unique brain state, incremental evidence indicates that these brain states are best understood as different interactions between the same basic psychological processes. By explicitly targeting the workings of these basic processes, while acknowledging the directive impact of context, we may be able to explain both the subjective quality of mental states and the basic building blocks of the mind at the same time.

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References

- Amodio, D. M., and Frith, C. D. (2006). Meeting of minds: The medial frontal cortex and social cognition. *Nature Reviews Neuroscience*, 7, 268–77.
- Andrews-Hanna, J. R., Reidler, J. S., Sepulcre, J., Poulin, R., and Buckner, R. L. (2010). Functional-anatomic fractionation of the brain's default network. *Neuron*, 65, 550–62.
- Barrett, L. F. (2006). Solving the emotion paradox: Categorization and the experience of emotion. *Personality and Social Psychology Review*, 10, 20–46.
- (2012). Emotions are real. *Emotion*, 12, 413–29.
- (2013). Psychological construction: A Darwinian approach to the science of emotion. *Emotion Review*, 5, 379–89.
- Barrett, L. F., and Bar, M. (2009). See it with feeling: Affective predictions in the human brain. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364, 1325–34.
- Barrett, L. F., and Bliss-Moreau, E. (2009). Affect as a psychological primitive. *Advances in Experimental Social Psychology*, 41, 167–218.
- Barrett, L. F., and Lindquist, K. A. (2008). The embodiment of emotion. In G. R. Semin and E. R. Smith (Eds.), *Embodied grounding: Social, cognitive, affective, and neuroscientific approaches*. New York: Cambridge University Press.
- Barrett, L. F., and Satpute, A. B. (2013). Large-scale brain networks in affective and social neuroscience: Towards and integrative functional architecture of the brain. *Current Opinion in Neurobiology*, 23, 1–12.
- Barrett, L. F., Wilson-Mendenhall, C. D., and Barsalou, L. W. (in press). A psychological construction account of emotion regulation and dysregulation: The role of situated conceptualizations. In J. J. Gross (Ed.), *The handbook of emotion regulation* (2nd ed.). New York: Guilford.
- Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, 22, 577–660.
- (2009). Simulation, situated conceptualization, and prediction. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364, 1281–89.
- Bastiaansen, J. A. C. J., Thoux, M., and Keysers, C. (2009). Evidence for mirror systems in emotions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364, 2391–2404.
- Boiger, M., and Mesquita, B. (2012). The construction of emotion in interactions, relationships and cultures. *Emotion Review*, 4, 221–29.

- Buckner, R. L., Andrews-Hanna, J. R., and Schacter, D. L. (2008). The brain's default network: Anatomy, function and relevance to disease. *Annals of the New York Academy of Sciences*, 1124, 1–38.
- Craig, A. D. (2009). How do you feel – now? The anterior insula and human awareness. *Nature Reviews Neuroscience*, 10, 59–70.
- Critchley, H. D., Wiens, S., Rotshtein, P., Ohman, A., and Dolan, R. J. (2004). Neural systems supporting interoceptive awareness. *Nature Neuroscience*, 7, 189–95.
- Cwir, D., Carr, P. B., Walton, G. M., and Spencer, S. J. (2011). Your heart makes my heart move: Cues of social connectedness cause shared emotions and physiological states among strangers. *Journal of Experimental Social Psychology*, 47, 661–64.
- Damasio, A. (2000). *The feeling of what happens: Body and emotion in the making of consciousness*. New York: Harcourt.
- Decety, J. (2011). Dissecting the neural mechanisms mediating empathy. *Emotion Review*, 3, 92–108.
- Dimberg, U. (1990). Facial electromyography and emotional reactions. *Psychophysiology*, 27, 481–94.
- Fan, Y., Duncan, N. W., De Greck, M., and Northoff, G. (2010). Is there a core network in empathy? An fMRI based qualitative meta-analysis. *Neuroscience & Biobehavioral Reviews*, 35, 903–11.
- Gallese, V., Keysers, C., and Rizzolatti, G. (2004). A unifying view on the basis of social cognition. *Trends in Cognitive Sciences*, 8, 396–403.
- Gallese, V., and Sinigaglia, C. (2011). What is so special about embodied simulation? *Trends in Cognitive Sciences*, 15, 512–19.
- Gross, J. J., and Barrett, L. F. (2011). Emotion generation and emotion regulation: One or two depends on your point of view. *Emotion Review*, 3, 8–16.
- Havas, D. A., Glenberg, A. M., and Rinck, M. (2007). Emotion simulation during language comprehension. *Psychonomic Bulletin & Review*, 14, 436–41.
- Herbert, C., Herbert, B. M., and Pauli, P. (2011). Emotional self-reference: Brain structures involved in processing of words describing one's own emotions. *Neuropsychologia*, 49, 2947–56.
- Herbert, B. M., and Pollatos, O. (2012). The body in the mind: On the relationship between interoception and embodiment. *Topics in Cognitive Science*, 4, 692–704.
- Hess, U., and Blairy, S. (2001). Facial mimicry and emotional contagion to dynamic emotional facial expressions and their influence on encoding accuracy. *International Journal of Psychophysiology*, 40, 129–41.
- Hess, U., and Fischer, A. H. (2013). Emotional mimicry as social regulation. *Personality and Social Psychology Review*, 17, 142–57.
- Jabbi, M., Bastiaansen, J., and Keysers, C. (2008). A common anterior insula representation of disgust observation, experience and imagination shows divergent functional connectivity pathways. *PLoS One* 3(8): e2939.
- Jack, R. E., Garrod, O. G. B., Yu, H., Caldara, R., and Schyns, P. G. (2012). Facial expressions of emotion are not universal. *Proceedings of the National Academy of Sciences of the United States of America*, 109, 7241–44.
- Keysers, K., and Gazzola, V. (2007). Integrating simulation and theory of mind: From self to social cognition. *Trends in Cognitive Sciences*, 11, 194–96.
- Kober, H., Barrett, L. F., Joseph, J., Bliss-Moreau, E., Lindquist, K. A., and Wager, T. D. (2008). Functional grouping and cortical-subcortical interactions in emotion: A meta-analysis of neuroimaging studies. *Neuroimage*, 42, 998–1031.
- Lamm, C., Decety, J., and Singer, T. (2011). Meta-analytic evidence for common and distinct neural networks associated with directly experienced pain and empathy for pain. *Neuroimage*, 54, 2492–2502.
- LeDoux, J. (2012). Rethinking the emotional brain. *Neuron*, 73, 653–76.
- Levenson, R. W., and Ruef, A. M. (1992). Empathy: A physiological substrate. *Journal of Personality and Social Psychology*, 63, 234–46.
- Lindquist, K. A., and Barrett, L. F. (2012). A functional architecture of the human brain: Insights from emotion. *Trends in Cognitive Sciences*, 16, 533–54.
- Lindquist, K. A., Wager, T. D., Kober, H., Bliss-Moreau, E. and Barrett, L. F. (2012). The brain basis of emotion: A meta-analytic review. *Behavioral Brain Sciences*, 35, 121–43.
- Lombardo, M. V., Chakrabarti, B., Bullmore, E. T., Wheelwright, S. J., Sadek, S. A., Suckling, J., et al. (2009). Shared neural circuits for mentalizing about the self and others. *Journal of Cognitive Neuroscience*, 22, 1623–35.
- Meier, B. P., Schnall, S., Schwarz, N., and Bargh, J. A. (2012). Embodiment in social psychology. *Topics in Cognitive Science*, 4, 705–16.

- Mosely, R., Carota, F., Hauk, O., Mohr, B., and Pulvermüller, F. (2012). A role for the motor system in binding abstract emotional meaning. *Cerebral Cortex*, 22, 1634–47.
- Niedenthal, P. M. (2007). Embodying emotion. *Science*, 316, 1002–5.
- Niedenthal, P. M., Winkielman, P., Mondillon, L., and Vermeulen, N. (2009). Embodiment of emotional concepts: Evidence from EMG measures. *Journal of Personality and Social Psychology*, 96, 1120–36.
- Northoff, G., Heinzel, A., de Greck, M., Bermpohl, F., Dobrowolny, H., and Panksepp, J. (2006). Self-referential processing in our brain – A meta-analysis of imaging studies on the self. *NeuroImage*, 31, 440–57.
- Oosterwijk, S., Lindquist, K. A., Anderson, E., Dautoff, R., Moriguchi, Y., and Barrett, L. F. (2012). Emotions, body feelings, and thoughts share distributed neural networks. *Neuroimage*, 62, 2110–28.
- Oosterwijk, S., Mackey, S., Wilson-Mendenhall, C. D., Winkielman, P., and Paulus, M. P. (submitted). Understanding language from within: Processing mental state language with internal or external focus involves different neural systems.
- Oosterwijk, S., Rottevel, M., Fischer, A. H., and Hess, U. (2009). Embodied emotion concepts: How generating words about pride and disappointment influences posture. *European Journal of Social Psychology*, 39, 457–66.
- Oosterwijk, S., Topper, M., Rottevel, M., and Fischer, A. H. (2010). When the mind forms fear: Embodied fear knowledge potentiates bodily reactions to fearful stimuli. *Social Psychological and Personality Science*, 1, 65–72.
- Oosterwijk, S., Winkielman, P., Pecher, D., Zeelenberg, R., Rottevel, R., and Fischer, A. H. (2012). Mental states inside out: Switching costs for emotional and non-emotional sentences that differ in internal and external focus. *Memory and Cognition*, 40, 93–100.
- Roy, M., Shohamy, D., and Wager, T. D. (2012). Ventromedial prefrontal-subcortical systems and the generation of affective meaning. *Trends in Cognitive Sciences*, 16, 147–56.
- Saxbe, D. E., Yang, X., Borofsky, L. A., and Immordino-Yang, M. H. (2013). The embodiment of emotion: Language use during the feeling of social emotions predicts cortical somatosensory activity. *Social, Cognitive and Affective Neuroscience*, 8(7), 806–12.
- Seeley, W. W., Menon, V., Schatzberg, A. F., Keller, J., Glover, G. H., Kenna, H., et al. (2007). Dissociable intrinsic connectivity networks for salience processing and executive control. *Journal of Neuroscience*, 27, 2349–56.
- Spreng, R. N., and Grady, C. L. (2010). Patterns of brain activity supporting autobiographical memory, prospection, and theory of mind, and their relationship to the default mode network. *Journal of Cognitive Neuroscience*, 22, 1112–23.
- Spunt, R. P., and Lieberman, M. D. (2011). An integrative model of the neural systems supporting the comprehension of observed emotional behavior. *Neuroimage*, 59, 3050–59.
- Touroutoglou, A., Lindquist, K. A., Hollenbeck, M., Dickerson, B. C., and Barrett, L. F. (under review). Intrinsic connectivity in the human brain does not reveal networks for “basic” emotions.
- Van Overwalle, F., and Baetens, K. (2009). Understanding others’ actions and goals by mirror and mentalizing systems: A meta-analysis. *Neuroimage*, 48, 564–84.
- Vrana, S. R., and Rollock, D. (2002). The role of ethnicity, gender, emotional content, and contextual differences in physiological, expressive, and self-reported emotional responses to imagery. *Cognition and Emotion*, 16, 165–92.
- Wager, T. D., Davidson, M. L., Hughes, B. L., Lindquist, M. A., and Ochsner, K. N. (2008). Prefrontal-subcortical pathways mediating successful emotion regulation. *Neuron*, 59, 1037–50.
- Waytz, A., and Mitchell, J. P. (2011). The mechanisms for simulating other minds: Dissociations between mirroring and self-projection. *Current Directions in Psychological Science*, 20, 197–200.
- Wicker, B., Keysers, C., Plailly, J., Royet, J. P., Gallese, V., and Rizzolatti, G. (2003). Both of us disgusted in my insula: The common neural basis of seeing and feeling disgust. *Neuron*, 40, 655–64.
- Willems, R. M., and Casasanto, D. (2011). Flexibility in embodied language understanding. *Frontiers in Psychology*, 2(116), 1–11.
- Wilson-Mendenhall, C. D., Barrett, L. F., and Barsalou, L. W. (2013). Neural evidence that human emotions share core affective properties. *Psychological Science*, 24, 947–56.
- Wilson-Mendenhall, C. D., Barrett, L. F., Simmons, W. K., and Barsalou, L. (2011). Grounding emotion in situated conceptualization. *Neuropsychologia*, 49, 1105–27.
- Winkielman, P., Niedenthal, P., and Oberman, L. (2008). The embodied emotional mind. In G. R. Semin and E. R. Smith (Eds.), *Embodied grounding: Social, cognitive, affective, and neuroscientific approaches* (pp. 263–88). New York: Cambridge University Press.

- Yeo, B. T., Krienen, F. M., Sepulcre, J., Sabuncu, M. R., Lashkari, D., Hollinshead, M., *et al.* (2011). The Organization of the human cerebral cortex estimated by functional connectivity. *Journal of Neurophysiology*, *106*, 1125–65.
- Zaki, J., Davis, J. I., and Ochsner, K. N. (2012). Overlapping activity in anterior insula during interoception and emotional experience. *Neuroimage*, *62*, 493–99.
- Zaki, J., Hennigan, K., Weber, J., and Ochsner, K. N. (2010). Social conflict resolution: Contributions of domain-general and domain-specific neural systems. *Journal of Neuroscience*, *30*, 8481–88.
- Zaki, J., and Ochsner, K. N. (2012). The neuroscience of empathy: Progress, pitfalls and promise. *Nature Neuroscience*, *15*, 675–80.
- Zaki, J., Weber, J., Bolger, N., and Ochsner, K. N. (2009). The neural basis of empathic accuracy. *Proceedings of the National Academy of Sciences of the United States of America*, *106*, 11382–87.

PART V

Applied embodied cognition

Memory, attention, and group cognition

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25

VISUAL EXPERIENCE

Michael Madary

In this chapter I will discuss a number of empirical approaches to conscious visual experience which fall under the general framework of embodied cognition. I will organize the chapter by treating the following topics in order: embedded and situated vision, extended vision, enactive vision, the dynamical systems approaches to vision, and the embodied neuroscience of vision. In the first five sections of the chapter, I will present each approach along with some common objections. In the final section, I will indicate questions for future investigation. As one might expect, there will be some overlap between the different approaches.

Embedded and situated vision

An embedded and situated approach to visual experience would place emphasis on the details of the embodiment of the visual system. This emphasis marks a clear departure from the orthodox computational approach to vision, an approach heavily influenced by David Marr (1983), in which the implementation of the visual system is thought to be of little importance. Embedded and situated approaches to vision, in contrast, suggest that the bodily details are crucial for understanding visual experience.

The details of embodiment reveal that human vision typically involves continuous eye and body movements. Action and visual perception seem to be interrelated in some important way. Eye-tracking devices show that humans typically saccade, which is to make a ballistic eye movement, three to four times per second (Findlay and Gilchrist, 2003). Even when we deliberately try to keep from saccading, we make involuntary eye movements described as drifts, tremors, or microsaccades (Martinez-Conde, Macknik, Troncoso, and Hubel, 2009). When precise devices are used to stabilize the retinal image by counteracting saccades, subjects experience temporary blindness (Riggs and Ratliff, 1952). Eye-tracking studies have shown that we naturally saccade towards areas in a visual scene which are rich in information relevant for our current goals.¹

In addition to these discoveries about eye movements, there are at least three other lines of evidence which suggest an important role for action in visual perception. The first involves selective rearing (Held and Hein, 1963), the second involves distortion goggles (Kohler, 1961; Taylor, 1962), and the third involves sensory substitution (Bach-y-Rita, 1972). Kevin O'Regan and Alva Noë (2001) have suggested that these lines of evidence indicate that human visual

perception requires an understanding of “sensorimotor contingencies,” which are the way appearances change due to self-generated movement.

In what remains of this section, I will discuss two main objections to the claim that action is tightly connected with visual experience. The first main objection is that the claim itself is not clear. Is it the strong claim that token actions are necessary for vision to occur, or is it something weaker? And if it is something weaker, who would deny it? Ken Aizawa, for instance, has attributed the stronger claim to Alva Noë (2004). Aizawa challenges Noë’s view by presenting examples of individuals under complete paralysis during surgery who reported having visual experiences while paralyzed (Aizawa, 2007, p. 23). These cases look to provide a counter-example to the stronger thesis about action and visual perception.

A second main objection to the connection between action and visual perception comes from what is known as the two-visual-systems hypothesis (Block, 2005; Jacob and Jeannerod, 2003). Human visual processing involves two physiologically distinct processing streams in cortex. The dorsal stream projects from primary visual cortex to posterior parietal cortex, and the ventral stream projects from primary visual cortex to inferotemporal cortex. According to the best-known version of the hypothesis (Milner and Goodale, 1995), dorsal processing is devoted to “vision for action” and is not available for consciousness. Ventral processing, in contrast, is devoted to “vision for perception” and can enter consciousness. In humans, the evidence for the hypothesis comes from lesion studies as well as the existence of illusions which affect conscious perception but not visually guided grasping. If vision for action is both unconscious and distinct from vision for perception, then the purported tight connection between action and visual perception may not be so tight after all.

Without entering into the details, here are two quick points about this objection. First, it seems obvious that conscious visual experience *can* guide action. But it is not clear that the hypothesis can accommodate this fact so long as we keep a strict distinction between vision for action and vision for perception (Briscoe, 2009; Noë, 2010). Second, another way to describe the differences between the two streams is to say that the dorsal stream is faster and devoted to peripheral vision, while the ventral stream is slower and devoted to central vision (Madary, 2011). This way of distinguishing the two streams accommodates the empirical evidence and avoids placing a wedge between action and visual perception.

Extended vision

Much of the research on *extended* cognition has focused on the possibility that unconscious mental states are partially constituted by entities outside of the brain (Clark and Chalmers, 1998; Menary, 2010). Some philosophers, however, have defended a thesis about the constitutive base of visual experience extending outside of the brain. They have defended something like the following thesis:

Externalism about the vehicles of perceptual states (EVPS): The vehicles of human conscious visual states can sometimes include the body and environment, in addition to the brain.

Both Susan Hurley and Alva Noë are known for defending EVPS. In this section, due to space limitations, I focus on Hurley’s argument for EVPS.²

This is one way of formulating Hurley’s argument in support of EVPS. I will discuss each premise in turn.

- (1) The subpersonal mechanisms of conscious vision are temporally extended.
- (2) Temporal extension can lead to spatial extension.
- (3) In the case of the human visual system, temporal extension does lead to spatial extension.

Conclusion: EVPS

The main inspiration behind (1) is Daniel Dennett's attack on the "Cartesian theater." The Cartesian theater is his name for the particular place in the brain in which experience happens, where "it all comes together" (1991, p. 107). By appealing to results from visual-masking experiments, Dennett makes the case that there is no Cartesian theater. Hurley picks up on this idea and attacks what she calls "temporal atomism," which is the view that each instant of visual consciousness is "carried by subpersonal processes moment by moment, snapshot by snapshot" (Hurley, 1998, p. 31). The alternative to temporal atomism is (1), or, in other words, the idea that the subpersonal processes which enable visual experience are always dynamic by nature; a frozen snapshot of neural activity does not determine any visual state (also see Noë, 2004, p. 218).

I take premise (2) from a passage of Hurley's published posthumously:

Temporal extension leads to spatial extension; Dennett (1991) famously made the intracranial version of this point in his arguments against a Cartesian theater, but the point extends promiscuously across the boundaries of skull and body.

(Hurley, 2010, p. 111)

What I take Hurley to mean here is that some systems have the following structure: if causal influences are traced over time, then we find an expanding spatial area which is a part of that system. As a matter of empirical fact, according to Hurley, human vision is such a system. Hurley's support for (3) is that, if "we track the causal arrow through time" in the human visual system, we find feedback loops at multiple spatial and temporal scales (1998, p. 307). Some feedback loops are neural, and some include the active body (Hurley, 1998, ch. 10). Further support for (3) can be found in dynamical systems approaches to vision, which I will cover below (p. 265).

The main objection to EVPS is that its proponents fail to distinguish causation from constitution (Block, 2005; Prinz, 2006; Adams and Aizawa, 2008).³ All parties agree that the body and the environment play an important causal role in conscious visual perception. But the opponents of EVPS see no need to make the further claim that the body and environment partially constitute the substrate of visual experience. It is tempting for proponents of EVPS to reject the distinction between causation and constitution, but note that this move may not be available: EVPS itself seems to depend on there being such a distinction. Hurley indicated that she would rather frame EVPS in terms of explanation rather than constitution versus "mere" causation (2010, pp. 113–14).

Don Ross and James Ladyman (2010) have made a strong contribution to the debate by arguing that the causal/constitutive distinction has no place in the mature sciences.

Enactive vision

"Sense-making" is a central theme within the *enactive* approach to cognition.⁴ Roughly, the idea is that meaning and significance emerge out of the interaction between an organism and its environment. This theme raises interesting issues for our understanding of visual experience. On one hand, the received view is that the content of visual experience is a representation of the objective world. On the other hand, according to the enactivist's commitment to sense-making,

one's environment is always partially determined by the interests and goals of the perceiver. To put the disagreement bluntly: do we see the world, or do we see the emergent result of our particular interaction with the world? In this section I will outline some of the enactivist's reasons for rejecting the received view.

The received view in the philosophy and science of perception is that vision has the task of representing the world around us more or less as it really is (Lewis, 1980, p. 239; Marr, 1983). Evan Thompson has described the received view as the "objectivist" view of representation (2007, p. 52). One of the main motivations for the objectivist view is it is reasonable to think that our visual representations must be accurate if they are to guide behavior in a successful way.

The enactivist, in contrast, rejects the supposition that an organism represents features of an objective world. Following Merleau-Ponty (1963), Thompson asserts that living organisms create meaning based on their own autonomous metabolic structure. A simple example of this process can be found in the behavior of bacterial cells. Some bacteria respond to sugar gradients in a solution by swimming against the gradient towards areas of greater sucrose concentration. Thompson elaborates:

While sucrose is a real and present condition of the physicochemical environment, the status of sucrose as a nutrient is not. Being a nutrient ... is enacted or brought forth by the way the organism, given its autonomy and the norms its autonomy brings about, couples with the environment.

(2007, p. 74)

If the interaction between organism and environment is one of "sense-making," as enactivism suggests, then there should be implications for human vision.

One way in which we might apply the enactivist concept of "sense-making" to vision would be to claim that the content of visual perception is always informed in some way by our own goals and interests. According to this claim, we do not simply see the objective world; we do not merely seek "to know what is where by looking" (Marr, 1983, p. 229). Instead, what we see depends in some way on the details of our own situation, similar to the way in which the nutritional status of sucrose depends on the metabolism of the bacterium. There are a number of lines of empirical evidence which can be cited in support of this claim. First, and perhaps most obviously, the evidence for task dependence on saccade patterns, sketched above, could be used. Another line of support would be evidence that sociocultural factors can influence visual experience (Bruner and Goodman, 1947; Boduroglu, Shah, and Nisbett, 2009). Another line of evidence available to the enactivist comes from neuroscience, which I will cover below (pp. 267–68).

One objection to this aspect of enactivism has been raised by Dennett, who claims that there is nothing new or revolutionary about enactivist sense-making:

As I and others have argued, all meaning in organisms is constructed by self-regarding processes that gerrymander the "given" categories of physics to suit their purposes.

(2011, p. 30)

He goes on to suggest that this idea can be found in Sellars, Quine, and "most AI systems" (*ibid.*). Thompson has replied that sense-making, as he intends it, can only be carried out by a system that has a particular kind of autonomy, a kind which is not found in most AI systems (2011, p. 189). Is enactivist sense-making a new and radical idea, or is it already widely accepted? I leave this question open.

The dynamical systems approach to vision

Modeling cognitive processes as *dynamical* systems has met with success in a number of areas of cognitive science (Port and van Gelder, 1995; Thelen and Smith, 1994; Spivey, 2007). One main way in which dynamical systems are relevant for vision will be familiar from the above remarks (pp. 264–65) on extended cognition; dynamical models of the physical substrate of visual experience might provide a motivation for EVPS, for the claim that the physical substrate of vision expands beyond the brain, and perhaps even the body.

Recall that EVPS is the thesis that the vehicles of perceptual states can sometimes extend beyond the brain, into the body and environment. One of Hurley's main motivations behind EVPS was that tracing the causal arrow over time leads to extended spatial boundaries of the system (premise (3) from the argument above). This idea can also be found in dynamical systems models. One common feature of dynamical systems is that the parts of the system do not always correspond to macroscopic physical boundaries. If those features can be found in the causal interactions between brain, body, and environment in visual perception, then we can construct dynamicist models which will include body and environment as a part of the system.

What remains to be seen is whether our best models of vision will be these kinds of dynamicist models. The main alternative would be internalist mechanistic models of the visual brain. Proponents of mechanistic explanation have voiced some of the most important objections to dynamical systems models of the mind. Carl Craver (2007), for instance, has argued that neuroscientific explanations should be mechanistic, that differential equations alone leave out something essential for the explanation. Apart from general worries about explanation with dynamical systems, one might also object to the practice of using dynamical systems theory in order to motivate claims about the spatial boundaries of physical systems.

The embodied neuroscience of vision

There are at least two emerging themes in neuroscience which converge on themes from embodied approaches to visual experience. They are, first, the context sensitivity of neural processing, and, second, neural models which give a central role to prediction, or anticipation, in the cycle of action and visual perception. As an historical note, although both of these themes are now slowly entering the mainstream, both themes are central to the pioneering work of Walter Freeman, who has been defending them, in one form or another, for several decades (Freeman, 1999).

The traditional understanding of the neuroscience of vision is in line with the objectivist view mentioned in the above section on enactivism. The objectivist maintains that the task of vision is to represent the objective world, without variation due to context or embellishment of other kinds. The neuroscientific tradition which most strongly supports this position dates back to the Nobel Prize-winning work of David Hubel and Torsten Wiesel (1959). They used single-cell recording to demonstrate that particular neurons in the cat brain fired strongly in response to particular visual stimuli. This method has since been widely used in support of the idea that visual neurons function as feature detectors. If visual neurons are strictly in the business of representing objective features in the world, then objectivism looks to be correct.

But there is another way of understanding neural processing which has been gaining increasing acceptance in the last couple of decades. This alternative suggests that neural processing is strongly context sensitive. On this view, the response of visual neurons depends only partly on the nature of the visual stimulus. The response of visual neurons also depends on other factors such as the ongoing endogenous dynamics within cortex (Arieli, Sterkin, Grinvald, and

Aertsen, 1996, perhaps also including what is known as the “default mode network,” Raichle *et al.*, 2001), the task that the organism is trying to accomplish (Cohen and Newsome, 2008), and bodily states of the organism (Horn and Hill, 1969; Abeles and Prut, 1996, as cited in Noë and Thompson, 2004). Amos Arieli and colleagues illustrate the main idea in a widely cited study on this theme as follows: “Thus, the effect of a stimulus [on cortex] might be likened to the additional ripples caused by tossing a stone into a wavy sea” (Arieli, Sterkin, Grinvald, and Aertsen, 1996, p. 1869).

Before moving on to the models of neural anticipation, I will make two quick comments about how context sensitivity might connect with some of the topics covered above. First, the ongoing dynamics of cortex could be used as support for premise (1) in my reconstruction of Hurley’s argument for EVPS. Second, in the debate between objectivism and enactivism, the objectivist can appeal to the evidence which shows visual neurons to be feature detectors, and the enactivist can appeal to the evidence for context sensitivity in visual neuronal response.⁵

The second emerging theme in neuroscience relevant here is the idea that the brain predicts or anticipates the upcoming sensory stimulation. In the case of vision, it is anticipation of the sensory consequences of bodily movement. An overview of the neuroscientific evidence which motivates this theme can be found in Kestutis Kveraga and colleagues (Kveraga, Ghuman, and Bar, 2007), in which they cover both neurophysiological evidence as well as mathematical models. The important neurophysiological features of cortex include two well-established facts. First, there are distinct visual pathways from the retina which process information at different speeds. This fact underlies the hypothesis that the faster processing enables anticipatory feedback to the slower pathway (Bullier, 2001). Second, there is massive feedback connectivity in the mammalian visual areas (Rockland and Van Hoesen, 1994). The traditional understanding of the feedback connections is that they are “merely” modulatory, but the newly emerging understanding of them is that they are predictive. There are a number of mathematical models of the visual brain which posit some kind of predictive processing (Rao and Ballard, 1999; Friston and Kiebel, 2009). These models fit nicely with recent work in the philosophy of perception which suggests that visual anticipation occurs at the conscious level (Siegel 2006; Madary, 2013).

Future directions for embodied approaches to visual experience

This final section of the chapter raises three areas of future research for embodied approaches to visual experience. These areas involve the nature of visual consciousness, the role of the brain for embodied approaches, and the question of visual representation.

The first area of future research has to do with the nature of visual consciousness itself. The orthodox view in the philosophy of perception is that, if visual experience has any content at all, then it is propositional content of some kind (Siegel, 2010). Often this content is described using natural language, as in Searle (1983, p. 41). It is not obvious that this way of describing visual content is compatible with some of the themes explored in this chapter. In particular, it is not clear that everyday linguistic reports can capture the content of visual experience if that content is anticipatory, closely bound up with action, dynamic, and enacted (as in sense-making, from pp. 265–66 above). Future work will determine whether and to what extent there is a real tension here.

The second area for future research has to do with the role of the brain. Perhaps owing to the influence of J. J. Gibson, embodied approaches to vision have sometimes urged a limited role for neuroscience as a way of explaining vision (O’Regan and Noë, 2001; Noë 2004; O’Regan, 2011). On the other hand, as explained above, some current trends in neuroscience

seem to converge on themes that are important to embodied vision researchers. Of particular interest here are Bayesian predictive-coding models of neural processing (Friston and Kiebel, 2009; Hohwy, 2013; Clark, 2013). Do these kinds of models support the theories of embodied vision researchers, or will the charge remain that the brain is the wrong place to look for understanding conscious vision?

The third area for future research has to do with visual representation. Traditionally, a representation refers to an information state with correctness conditions (Fodor, 1987; Dretske, 1995). Will our best models of vision include representations? There are a number of related questions here. For instance, one might distinguish between personal and subpersonal representations. Does it make sense to posit representations at one level and not the other? There has been a good bit of debate over whether dynamical systems models of the mind involve representations (van Gelder, 1995; Bechtel, 1998). As long as we use dynamical systems to model vision, then this debate may be relevant. Similarly, the disagreement between objectivist and enactivist stances is relevant here. If the enactivist is correct that our visual experience is partly determined by our own interests and so forth, then can such an experience be described in terms of personal-level representational content? In other words, can there be correctness conditions for content which is the result of enactivist sense-making?

Notes

- 1 The early classic studies were carried out by Alfred Yarbus (1967). Due to the nature of early eye trackers, Yarbus' experiments were confined to the laboratory. In the 1990s, Michael Land and colleagues used mobile lightweight trackers to confirm the influence of task on eye movements in natural environments (see Land, Mennie, and Rusted, 1999, for example). Along the same lines, Dana Ballard and colleagues have shown that subjects use eye movements for "pointing" purposes as an efficient strategy for completing cognitive tasks (Ballard, Hayhoe, Pook, and Rao, 1997). Excellent overviews can be found in Findlay and Gilchrist (2003, ch. 7) and Hayhoe and Ballard (2005).
- 2 Some of this material is covered in my 2012 in more detail.
- 3 There are at least two other objections to be found in the literature. The first is that brain stimulation alone is sufficient for visual experiences (Penfield and Jasper, 1954; Prinz, 2006). The second objection is that dreaming involves visual experiences without the active body. For Noë's defense of EVPS against these objections, see his 2004, pp. 209–15.
- 4 The term "enactivism" is used in slightly different ways in the literature. Here I understand the term to reflect an approach to the mind associated with the works of Humberto Maturana, Francisco Varela, and Evan Thompson. I regard Thompson's 2007 to be the most comprehensive expression of this approach.
- 5 For a non-visual neurophysiological case against objectivism, see Kathleen Akins (1996), who focused on the human thermoreceptive system.

References

- Abeles, M., and Prut, Y. (1996). Spatio-temporal firing patterns in the frontal cortex of behaving monkeys. *Journal of Physiology*, 90, 249–50.
- Adams, F., and Aizawa, K. (2008). *The bounds of cognition*. Malden, MA: Blackwell.
- Aizawa, K. (2007). Understanding the embodiment of perception. *Journal of Philosophy*, 104, 5–25.
- Akins, K. (1996). Of sensory systems and the "aboutness" of mental states. *Journal of Philosophy*, 93, 337–72.
- Arieli, A., Sterkin, A., Grinvald, A., and Aertsen, A. (1996). Dynamics of ongoing activity: Explanation of the large variability in evoked cortical responses. *Science*, 273, 1868–71.
- Bach-y-Rita, P. (1972). *Brain mechanisms in sensory substitution*. New York: Academic Press.
- Ballard, D., Hayhoe, M., Pook, P., and Rao, R. (1997). Deictic codes for the embodiment of cognition. *Behavioral and Brain Sciences*, 20, 723–67.
- Bechtel, W. (1998). Representations and cognitive explanations: Assessing the dynamicist challenge in cognitive science. *Cognitive Science*, 22, 295–318.

- Block, N. (2005). Review of the book *Action in Perception*, by Alva Noë. *Journal of Philosophy*, 5, 259–72.
- Boduroglu, A., Shah, P., and Nisbett, R. (2009). Cultural differences in allocation of attention in visual information processing. *Journal of Cross-Cultural Psychology*, 40, 349–60.
- Briscoe, R. (2009). Egocentric spatial representation in action and perception. *Philosophy and Phenomenological Research*, 2, 423–60.
- Bruner, J., and Goodman, C. (1947). Value and need as organizing factors in perception. *Journal of Abnormal and Social Psychology*, 42, 33–44.
- Bullier, J. (2001). Feedback connections and conscious vision. *Trends in Cognitive Sciences*, 5, 369–70.
- Clark, A. (2013). Whatever next? Predictive brains, situated agents, and the future of cognitive science. *Behavioral and Brain Sciences*, 36, 181–204.
- Clark, A., and Chalmers, D. (1998). The extended mind. *Analysis*, 58, 10–23.
- Cohen, M., and Newsome, W. (2008). Context-dependent changes in functional circuitry in visual area MT. *Neuron*, 60, 162–73.
- Craver, C. (2007). *Explaining the brain*. Oxford: Oxford University Press.
- Dennett, D. (1991). *Consciousness explained*. Boston: Little, Brown.
- (2011). Shall we tango? No, but thanks for asking. *Journal of Consciousness Studies*, 18, 23–34.
- Dretske, F. (1995). *Naturalizing the mind*. Cambridge, MA: MIT Press.
- Findlay, J. M., and Gilchrist, I. (2003). *Active vision*. Oxford: Oxford University Press.
- Fodor, J. (1987). *Psychosemantics*. Cambridge, MA: MIT Press.
- Freeman, W. (1999). *How brains make up their minds*. London: Weidenfeld & Nicolson.
- Friston, K., and Kiebel, S. J. (2009). Predictive coding under the free-energy principle. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364, 1211.
- Hayhoe, M., and Ballard, D. (2005). Eye movements in natural behavior. *Trends in Cognitive Science*, 9, 188–94.
- Held, R., and Hein, A. (1963). Movement produced stimulation in the development of visually guided behavior. *Journal of Comparative and Physiological Psychology*, 56, 873–76.
- Hohwy, J. (2013). *The predictive mind*. Oxford: Oxford University Press.
- Horn, G., and Hill, R. (1969). Modifications of the receptive field of cells in the visual cortex occurring spontaneously and associated with bodily tilt. *Nature*, 221, 185–87.
- Hubel, D., and Wiesel, T. (1959). Receptive fields of single neurones in the cat's striate cortex. *Journal of Physiology*, 148, 574–91.
- Hurley, S. (1998). *Consciousness in action*. Cambridge, MA: Harvard University Press.
- (2010). The varieties of externalism. In R. Menary (Ed.), *The extended mind*. Cambridge, MA: MIT Press.
- Jacob, P., and Jeannerod, M. (2003). *Ways of seeing: The scope and limits of visual cognition*. Oxford: Oxford University Press.
- Kohler, I. (1961). Experiments with goggles. *Scientific American*, 206, 62–86.
- Kveraga, K., Ghuman, A., and Bar, M. (2007). Top-down predictions in the cognitive brain. *Brain and Cognition*, 65, 145–68.
- Land, M., Mennie, N., and Rusted, J. (1999). The roles of vision and eye movements in the control of activities of everyday living. *Perception*, 28, 1311–28.
- Lewis, D. (1980). Veridical hallucination and prosthetic vision. *Australasian Journal of Philosophy*, 58, 239–49.
- Madary, M. (2011). The dorsal stream and the visual horizon. *Phenomenology and the Cognitive Sciences*, 10, 423–38.
- (2012). Showtime at the Cartesian theater? Vehicle externalism and dynamical explanations. In F. Paglieri (Ed.), *Consciousness in interaction*. Amsterdam: John Benjamins Publishing.
- (2013). Anticipation and variation in visual content. *Philosophical Studies*, 165, 335–47.
- Marr, D. (1983). *Vision*. New York: W. H. Freeman & Sons.
- Martinez-Conde, S., Macknik, S., Troncoso, X., and Hubel, D. (2009). Microsaccades: A neurophysiological analysis. *Trends in Neuroscience*, 9, 463–75.
- Menary, R. (Ed.) (2010). *The extended mind*. Cambridge, MA: MIT Press.
- Merleau-Ponty, M. (1963). *The structure of behavior* (A. Fisher, Trans.). Pittsburgh, PA: Duquesne University Press.
- Milner, A. D., and Goodale, M. A. (1995). *The visual brain in action*. Oxford: Oxford University Press.
- Noë, A. (2004). *Action in perception*. Cambridge, MA: MIT Press.
- (2010). Vision without representation. In N. Gangopadhyay, M. Madary, and F. Spicer (eds.), *Perception, action, consciousness: Sensorimotor dynamics and two visual systems*. Oxford: Oxford University Press.

- Noë, A., and Thompson, E. (2004). What is a neural correlate of consciousness? *Journal of Consciousness Studies*, 11, 3–28.
- O'Regan, K. (2011). *Why red doesn't sound like a bell*. Oxford: Oxford University Press.
- O'Regan, K., and Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, 24, 939–1031.
- Penfield, W., and Jasper, H. (1954). *Epilepsy and the functional anatomy of the human brain*. Boston: Little, Brown.
- Port, R., and van Gelder, T. (eds.) (1995). *Mind as motion*. Cambridge, MA: MIT Press.
- Prinz, J. (2006). Putting the breaks on enactive perception. *Psyche*, 12. Retrieved from <http://psyche.cs.monash.edu.au/>
- (2012). *The conscious brain*. Oxford: Oxford University Press.
- Raichle, M., MacLeod, A. M., Snyder, A. Z., Powers, W. J., Gusnard, D. A., and Shulman, G. L. (2001). A default mode of brain function. *Proceedings of the National Academy of Sciences of the United States of America*, 98, 676–82.
- Rao, R. P. N., and Ballard, D. (1999). Predictive coding in the visual cortex: A functional interpretation of some extra-classical receptive-field effects. *Nature Neuroscience*, 2, 9–87.
- Riggs, L. A., and Ratliff, F. (1952). The effects of counteracting the normal movements of the eye. *Journal of the Optical Society of America*, 42, 872–73.
- Rockland, K., and Van Hoesen, G. (1994). Direct temporal-occipital feedback connections to striate cortex (V1) in the macaque monkey. *Cerebral Cortex*, 4, 300–13.
- Ross, D., and Ladyman, J. (2010). The alleged coupling–constitution fallacy and the mature sciences. In R. Menary (Ed.), *The extended mind*. Cambridge, MA: MIT Press.
- Searle, J. (1983). *Intentionality*. Cambridge: Cambridge University Press.
- Siegel, S. (2006). Subject and object in the contents of visual experience. *Philosophical Review*, 115, 355–88.
- (2010). The contents of perception. E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy*. Retrieved from <http://plato.stanford.edu/entries/perception-contents/>
- Spivey, M. (2007). *The continuity of mind*. Oxford: Oxford University Press.
- Taylor, J. (1962). *The behavioral basis of perception*. New Haven, CT: Yale University Press.
- Thelen, E., and Smith, L. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge, MA: MIT Press.
- Thompson, E. (2007). *Mind in life*. Cambridge, MA: Harvard University Press.
- (2011). Reply to commentaries. *Journal of Consciousness Studies*, 18, 176–223.
- van Gelder, T. (1995). What might cognition be if not computation? *Journal of Philosophy*, 92, 345–81.
- Yarbus, A. (1967). *Eye movements and vision*. New York: Plenum Press.

FIRST-ORDER EMBODIMENT, SECOND-ORDER EMBODIMENT, THIRD-ORDER EMBODIMENT

Thomas Metzinger

Introduction: the self grounding problem

This chapter focuses on the relationship between embodiment and the phenomenology of selfhood. Specifically, it looks at the notion of *minimal phenomenal selfhood* (MPS; see pp. 000–00, below), which defines the research target of isolating the minimal set of conditions constituting the conscious experience of “being a self,” relative to a given class of systems. In preparation, I will introduce three new working concepts: “first-order embodiment” (1E), “second-order embodiment” (2E), and “third-order embodiment” (3E).¹ Each of these concepts picks out a rather well-defined class of systems: 1E-systems are reactive, adaptive systems, achieving intelligent behavior without explicit computation; 2E-systems increase their level of causal self-control by explicitly and holistically representing themselves *as* embodied; and 3E-systems integrate certain aspects of their body model into a unified ontology, thereby elevating them to the level of conscious experience. A normal, conscious human being walking down the street in an ordinary, non-pathological state of consciousness simultaneously is a member of all three classes at the same time. This may be interestingly different, or not true at all, in certain alternative configurations like dreamless sleep, epileptic absence seizures, dreaming, or experimentally induced full-body illusions (FBIs). Here, my goal lies in drawing attention to a new version of the mind-body problem: How, precisely, do we describe the *grounding relations* holding between 1E, 2E, and 3E? In analogy to the “symbol grounding problem” one might also call this the “self grounding problem” (Harnad, 1990; Barsalou, 2008). It is the problem of describing the abstract computational principles as well as the implementational mechanics by which a system’s phenomenal self-model (PSM; cf. Metzinger, 2003a, 2007) is anchored in low-level physical dynamics, in a maximally parsimonious way, and without assuming a single, central module for global self-representation.

1E, 2E, and 3E

First-order embodiment can be found, for instance, in bio-robotics and in all “bottom-up approaches” to artificial intelligence. Conceptually, this class of systems can be defined on a microfunctionalist or dynamicist level of description (Clark, 1993; Chemero, 2009). The basic

idea is to investigate how intelligent behavior and other complex system properties, which we previously termed “mental,” can naturally evolve out of the dynamical, self-organizing interactions between the environment and a purely physical, reactive system that does not possess anything like a central processor, “software,” or explicit computation of the different behaviors. Here, a leading theoretical intuition is that explicit representation is not necessary to generate complex forms of behavior, because the “the body is its own best model” (Brooks, 1991) and behaviors may emerge from the cooperation of low-level procedures, including properties of the environment. For research aimed at 1E, the relevant questions are: How was it possible for the very first forms of pre-rational intelligence to emerge in a physical universe? How could we *acquire* a flexible, evolvable, and coherent behavioral profile in the course of natural evolution? How is it possible to gradually generate intelligent behavior without explicit computation?

Second-order embodiment means that a system *represents* itself as embodied. Conceptually, this class of systems is picked out on the representationalist level of description because the emergence of 2E is determined by *representational* properties, namely, the possession of a body model. Second-order embodiment is a property that can be ascribed to any system that satisfies the following three conditions: first, we can successfully understand the intelligence of its behavior and other seemingly “mental” properties by describing it as a *representational* system; second, this system has a single, explicit, and coherent self-representation of itself *as being an embodied agent*; and, third, the way in which this system *uses* this explicit internal model of itself as an entity possessing and controlling a body helps us understand its intelligence and its psychology in functional terms. Typically, an unconscious body schema used in motor control could serve as the functional vehicle for realizing 2E. For example, some advanced robots, many primitive animals on our planet, and possibly sleepwalking human beings or patients showing complex behavior during certain epileptic absence seizures are plausible examples of 2E. However, the traditional notion of a “body schema” is vague (Gallagher, 2005, p. 17; de Vignemont, 2010; Alsmith and de Vignemont, 2012, p. 3). Currently, it has become the target of a fresh approach by modern cognitive neuroscience and robotics (e.g. Maravita, Spence, and Driver, 2003; Haggard and Wolpert, 2005; Hoffmann *et al.*, 2010).

In evolutionary bio-robotics, resilient systems have been developed that evolve continuous control of effectors with the help of a topological bodily self-model, indirectly inferring their own morphology through self-directed exploration and then using the resulting self-models to synthesize new behaviors (e.g. Gloye, Wiesel, Tenchio, and Simon, 2005; Bongard, Zykov, and Lipson, 2006; Schmidhuber, 2007). An excellent recent example of 2E can be found in the work of Holke Cruse and Malte Schilling (e.g. Schilling and Cruse, 2012). Their MMC-body model holistically encodes kinematic relationships between body parts in a recurrent neural network and can be used for prediction, sensor fusion, or inverse modeling (“MMC” stands for a specific principle of integration, the “mean of multiple computation”; see Cruse and Steinkühler, 1993; Cruse, Steinkühler, and Burkamp, 1998). In itself the body model cannot, of course, initiate or actively “construct” any behaviors (like the proverbial little man in the head), but in the context of the system as a whole it can function as a new tool – namely a grounded, predictive body model that continuously filters data in accordance with geometrical, kinematic, or dynamic boundary conditions. On a certain level of functional granularity, this type of core representation might also describe the generic, universal geometry which is *shared* by all members of a biological species. Therefore, it is conceivable how such a body model could support unconscious social cognition via 2E: an integrated body model is a new window into the social world (Metzinger, 2003a, 2009, ch. 9; Metzinger and Gallese, 2003). A second interesting feature demonstrated by this specific example is that 2E-systems can in principle *alternate* between physical and virtual behavior. A body model could be used in simulating and predicting

potential new solutions to a problem posed by the environment, with the physical body then testing various new behavioral solutions. Whereas a 1E system could be adaptive, only a 2E system could truly learn, because a self-model seems to be strictly necessary for the development of new behavioral patterns, just as a world model is necessary for the evaluation of causal structures (Ay and Zahedi, 2013, p. 502; Zahedi, Ay, and Der, 2010). Learning, in this sense, directly increases the level of causal self-control. This clearly is a new level of embodied intelligence, because it adds flexibility and sensitivity to a wider temporal context, plus a new possibility for actively exploring and appropriating the causal structure of the world, thereby considerably increasing the volume of the system's space of possible behaviors. This is a new *order* of embodiment, because the very fact of embodiment *as such* is now explicitly represented in the system itself.

Third-order embodiment is the special case in which a physical system not only explicitly models itself *as* an embodied being, but also maps some of the representational content generated in this process onto the level of conscious experience. This third-order embodiment is found in conscious human beings in ordinary wake states, in dreams, but also during naturally occurring altered states like out-of-body experiences (OBEs) or experimentally induced full-body illusions (FBIs; see p. 280, below; Metzinger, 2009, 2010, for an accessible introduction). It is plausible to assume that many higher animals often are examples of 3E as well: they would then have an online model of their own body as a whole, which has been elevated to the level of global availability and integrated with a single spatial situation model plus a virtual window of presence. Therefore, they can have the conscious experience of being situated as bodily selves while *owning* affective or sensorimotor states.²

Consequently, to fully understand 3E, one ultimately needs a comprehensive theory of consciousness (Metzinger, 1995, 2000). But what is conscious experience? Here is one very short answer: it is the functional level of granularity on which an information-processing system first generates a unified ontology, that is, an explicit and integrated set of assumptions about what exists and what does not, a single and integrated world model under which it now operates. In 3E systems, the body has become a part of this unified ontology. Third-order embodiment means that a given system consciously *experiences* itself as embodied, that the body is for the first time explicitly represented as *existing*, that a given organism or robot possesses a specific type of “phenomenal self-model” (Metzinger, 2003a, 2007).

The functional reason why we experience our own bodies as untranscendably real is that the bodily partition of our PSM is transparent. “Transparency” is here used to refer to an exclusive property of phenomenal states, meaning that the fact of their being *representational* states is inaccessible to introspective attention. Metaphorically speaking, the construction process is “invisible” on the level of phenomenal experience itself (Metzinger 2003a, §3.2.7; 2003b, p. 354). Phenomenal transparency explains why we *identify* with the content given via 3E. One of the main challenges in describing the step from conscious body representation to the phenomenal property of “selfhood” includes the subjective sense of identification, which also assigns a unique role to *this* body among all the other bodies potentially represented on the level of conscious experience as well. Those proprio- and interoceptive layers of the PSM that are constantly active may play a decisive role here (Seth, Suzuki, and Critchley, 2012; Seth, 2013). The central defining characteristic of 3E refers to the class of systems generating the phenomenology of body identification (i.e. the subjective sense of being identical with the contents of one specific body model, even if there is a social scene including other models of embodied agents³).

Equally important is a given conscious system's capacity for self-location in a spatio-temporal frame of reference. The phenomenal target property that has to be grounded is not only *my*

body (consisting of identity as passively experienced, plus the implicit potential for active ownership via global control), but *my body here and now*. Conceptually, three conditions are central. First, the relevance of the phenomenological level of analysis: only 3E systems possess bodily self-consciousness, and as 1E and 2E systems do not possess the relevant set of phenomenal properties, no relevant phenomenological truths can be expressed about them.⁴ Second, a whole set of new and interesting functional properties emerges, such as the availability of global properties for attention: the system can now for the first time turn the body *as a whole* into an object of self-directed attention, thereby making its own *global* properties the target of computational resource allocation, second-order statistics, selective motor control, or self-directed concept formation. The capacity for explicit self-location in a single, integrated spatio-temporal frame of reference, and on the level of global availability,⁵ enables more flexible and context-sensitive forms of global self-control in the motor domain, but also for cognitive tasks (such as remembering past states or planning future goal states of the system *as a whole*, now importantly assuming trans-temporal identity, e.g. that action consequences like future reward events will be related to the *same* organism). Third, the functional integration of spatio-temporal self-location and the pre-reflective identification with the content of a currently active body model generate a specific new phenomenal property: we can now conceptualize the simplest form of self-consciousness as “transparent situatedness in time and space,” namely the phenomenology of *Anwesenheit*, of being-present-as-an-embodied-self.

Example 1: “visual attentional agency”

At this point, it is particularly interesting to introduce a first set of empirical data-points. We must acknowledge the fact that body representation can be absolutely minimal while a robust, stable sense of selfhood is preserved: empirical research on OBEs and particularly on dreaming demonstrates that transparent self-location is enough to bring about a minimal form of self-consciousness.⁶ That said, more complex forms of 3E can, and frequently do, arise in dreams and OBEs, raising the question of how they are grounded in 1E and 2E. But data clearly show that there exists a *limiting case* of 3E, namely a minimal, yet robustly self-conscious form of self-location without explicit embodiment in any interesting sense. This limiting case may be important for grounding the PSM. Let me illustrate the relevance of these findings by giving an example from my own work. In earlier publications, I have claimed that the dream state, which is accompanied by sleep paralysis, is often an example of explicit body representation (we experience a dream body), but in the absence of 1E, because the physical body is inert and fully paralyzed. Dreamers, therefore, are not fully embodied agents (e.g. Metzinger 2003a, p. 256; 2009). The functional disembodiment hypothesis (cf. Windt, in press) says that the dream state is characterized by a functional disconnection from the sleeping body such that real-body inputs do not enter into the dream and internally experienced dream movements are not enacted by the sleeping body.

However, I also pointed out a single, highly interesting exception, namely the reliable directional correspondence between dream eye movements and real eye movements: there is at least one sense in which the phenomenal dream self is not completely disembodied in the functional sense (Metzinger, 2003a, p. 261). For example, the spatial correlation between eye movements in the dream body and the physical body has served as the foundation for a number of ingenious studies homing in on the neural correlate of “lucidity” (i.e. the rare occurrence of realizing that one is dreaming during the dream state itself; see LaBerge, Stephen, Nagel, Dement, and Zarcone, 1981; Voss, Holzmann, Tuin, and Hobson, 2009; Voss, Schermelleh-Engel, Windt, Frenzel, and Hobson, 2013; Dresler *et al.*, 2012 – for discussion see Metzinger, 2003a;

Windt and Metzinger, 2007; Windt, in press). In these experiments, lucid dreamers actively send signals to the experimenter via deliberate eye movements, which can be read off the EOG (electrooculogram) and are retrospectively confirmed by the dreamers themselves. This discovery is theoretically important, because it gives us a first candidate for a fine-grained *grounding relation* connecting 3E (the conscious dream body) with low-level physical dynamics (measurable, local neural activity controlling eye movements), plausibly mediated via 2E (i.e. a specific aspect of an unconscious body model mediating the active exploration of visual space). Phenomenal self-consciousness and self-related cognition can be grounded in different ways, including neurally realized simulations, bodily processes, and situated action (Barsalou, 2008, p. 619). Interestingly, here we find all three of them: gaze control in the lucid dream state clearly is a form of virtually situated action involving motor control plus attentional resource allocation in a virtual environment; it uses an internal simulation of the body-as-visually-attending (the PSM of the dream state; see Windt and Metzinger, 2007, and Windt, in press, for details); and it has dynamic, structure-preserving bodily correlates. The successful control of gaze direction in the lucid dream state is what anchors selective, high-level visual attention (including the conscious sense of “attentional agency,” cf. Metzinger, 2013b, p. 8) in low-level, non-representational features of bodily movement. Here we have an example of a specific and functionally persistent grounding relation connecting 1E, 2E, and 3E in a situation where most of these relations only hold between 2E and 3E and most functions of self-consciousness are not grounded in 1E.

The *generalized* version of the functional disembodiment claim, however, has now been refuted, as it can be shown that more than one minimal form of functional embodiment is preserved during REM (rapid-eye-movement)-sleep dreams (cf. Windt, in press). Real-body stimulation (e.g. sprays of water on the skin, Dement and Wolpert, 1958; electric stimulation, Koulack, 1969; blood-pressure-cuff stimulation on the leg, Nielsen, 1993; Sauvageau, Nielsen, Ouellet, and Montplaisir, 1993; Nielsen, Ouellet, and Zadra, 1995; Sauvageau, Nielsen, and Montplaisir, 1998; vestibular stimulation, Hoff, 1929; Hoff and Plötzl, 1937; Leslie and Ogilvie, 1996) is frequently incorporated in dreams, and indeed it has been suggested that many typical dream themes – such as dreams of flying, falling, or being unable to move or flee from a pursuer – can be explained in terms of illusory own-body perception (Schönhammer, 2004, 2005), and the same may be true for sleep-paralysis nightmares during sleep onset (Cheyne, Rueffer, and Newby-Clark, 1999; Cheyne, 2003, 2005). An early predecessor of this view of dreams as *weakly functionally embodied* states (Windt, in press) is the *Leibreiztheorie*, promoted by nineteenth-century researchers and extensively discussed and rejected by Freud (1899/2003, pp. 38–56). On the output side, there is also ample evidence for dream-enactment behavior in healthy subjects (e.g. Nielsen, Svob, and Kuiken, 2009) and patients with RBD (REM-sleep behavior disorder; see Schenck, 2005, 2007), as well as some evidence from lucid dreaming suggesting that dream movements are accompanied by measurable muscle twitches in the corresponding limbs and changes in heart and respiration rate (LaBerge *et al.*, 1981; LaBerge and Dement, 1982; LaBerge, Greenleaf, and Kedzierski, 1983; Fenwick *et al.*, 1984; Schredl and Erlacher, 2008).

Are there any empirical examples of bodily experience in dreams being created completely offline, in the absence of 1E and 2E? At the very least, it would be hard to see how there could be any empirical evidence for saying that such instances of functionally disembodied 3E exist in dreams: state-of-the-art studies investigating the sensory input blockade (Hobson *et al.*, 2000), or, as Dang-Vu *et al.* more aptly call it, the “reduced sensitivity to external salient stimuli” (Dang-Vu *et al.*, 2005, p. 417) during REM sleep not only explicitly acknowledge that the degree of sensory incorporation is weakened rather than completely absent in REM sleep, but also use stimulus incorporation as an important means of *studying* the underlying mechanisms in

the first place. This suggests that the most plausible and parsimonious explanation of bodily experience in dreams, as well as the most effective methods used in its study, will appeal to its real-bodily basis. Of course, none of this is to say that 3E in the absence of 1E and 2E is impossible; but it is to say that its existence would be hard to establish empirically and sheds doubt on my own original claim that dreams are a real-world and empirically well-established example of bodily experience arising during a functionally disembodied state.

Grounding relations connecting 1E, 2E, and 3E

What is a “grounding relation”? A grounding relation connects a given intentional and/or phenomenal target property with the situated, low-level physical dynamics of a given type of cognitive and/or conscious system, for example by specifying a computational model that allows us to understand the transition from the representational or phenomenological level of description to the one of physical microdynamics. Such a grounding relation may span many levels of description and may therefore be decomposable into subrelations connecting descriptions on different levels of granularity and in widening domains. If we accept the modeling component as methodologically essential, we may speak of “computationally grounded cognition” and think of a corresponding cascade involving the local grounding of a given mental target property via neural dynamics, embodiment, and situatedness (Pezzulo *et al.*, 2013, p. 4). From a philosophy-of-science perspective, three steps have to be taken. First, in dealing with phenomenal properties like “selfhood,” these have to be analyzed as *representational* structures (e.g. “transparency,” “self-location,” “egocentric frame of reference,” etc.). Second, we have to develop a computational model or other formalism that allows these structures to “bottom out.” This means that we need a better understanding of representationality as a *graded* property, as something that is not an all-or-nothing affair but permits degrees of constraint satisfaction. Such constraints could be spelled out in terms of stimulus correlation, decouplability, degrees of statistical covariance with body or environment, structural resemblance to the causal structure of the world, minimized prediction error, etc. Third, and perhaps most importantly, we must carefully distinguish between causally enabling and metaphysically necessary conditions, between the acquisition history and those properties *constituting* our respective target phenomenon (Blanke and Metzinger, 2009, box 1; Weber and Vosgerau, 2012, p. 60). Grounding is about constitution. For phenomenal properties (like “selfhood” or “identification”) we can expect a strictly local grounding, for example in contemporaneous states of the brain, and we know that local supervenience ultimately collapses into identity.⁷ For intentional, representational, or semantic properties, the system’s interaction history – in some cases even including social interactions within a linguistic community – plausibly will play a stronger role.

Let us now briefly look at the relationship between 1E, 2E, and 3E, while keeping our first example of a specific, to-be-grounded target property in mind. First-order embodiment describes a different class of systems than 2E and 3E. Therefore, it would be logically possible to have systems exhibiting 2E and/or 3E, but not 1E. In our world, however, 3E and 2E “ride” on 1E. Our first phenomenal target property (“visual attentional agency”) is determined by a complex functional property, which in turn is locally realized by a specific bodily process. Consciously experienced eye movements are grounded in this process, which can be computationally modeled. The next logical step will have to be a formal specification spanning all three levels of description, a computational model that describes the PSM in the dream and wake states, plus the role of the unconscious body model in *linking* virtual and physical control of eye movements, as well as the dynamics in the local neural correlate, generating testable predictions. This then would be what Barsalou (2008, p. 635) has called “transitioning from

demonstration experiments to analytic experiments.” As soon as the target phenomenon has been well documented, we want to reveal the underlying formal principles.

Obviously, in our world, there are many systems exhibiting pure 1E, and probably many biological systems belong to the conjunction of 1E and 2E (like the stick insects that are the modeling target of Cruse and Schilling). But is it logically possible to have 3E and 2E in the absence of 1E? Perhaps we could imagine Cartesian souls in heaven, constantly misrepresenting themselves as embodied, dreaming the dream of incarnation. But their dreams and their misrepresentations would then be ungrounded in any sort of physical history or dynamics, and it may be difficult to understand how they could be *about* spatial and temporal properties in the first place, how ungrounded semantic content is possible. The existence of such systems might be logically possible – but even so, it doesn’t seem conceivable how we could have observable and replicable scientific evidence for their disembodied existence. However, 1E, 2E, and 3E are here primarily meant to be used as epistemic notions, conceptual instruments developed for philosophy of cognitive science; and in the context of empirical research programs, this possibility is irrelevant.

But maybe one could have conscious embodiment in the absence of representation. Would it be logically possible to have 3E without 1E or 2E? In a specific kind of idealist metaphysics, one might assume that only phenomenal properties are real, and that ultimately neither physical nor representational properties exist. Third-order embodiment would then be pure appearance, a stand-alone phenomenal configuration. Here – if everything is phenomenal – the problem is to specify what the term “phenomenal” would mean. However, an example of a much more interesting, and heuristically fruitful, question would be the following: In our world, could there be *self-consciousness without representation*? Above, I have stipulated that 3E involves a mapping of representational content to consciousness. But perhaps scientific progress will ultimately allow us to drop this metatheoretical assumption in order to arrive at an even more parsimonious conceptual framework: Can 1E and 3E be simultaneously instantiated in a single system, can we have bodily self-consciousness without any form of representation? Or is an integrated body model strictly (nomologically) necessary?

However, the three notions of 1E, 2E, and 3E are primarily supposed to function as epistemic concepts, not as metaphysical ones. I believe that, if properly viewed as windows into different layers of embodiment, they might make a contribution as instruments possessing fecundity, in terms of helping us understand what exactly the real issues are – at this specific point in time, during this phase of scientific progress. Using the conceptual tools of 1E, 2E, and 3E, one can now formulate many relevant questions in a more precise way: Under the laws of nature holding in our universe (leaving logically possible worlds aside for a moment), what are the relevant, necessary and sufficient grounding relations connecting 1E, 2E, and 3E? How exactly is explicit, but unconscious, body representation grounded in the self-organizing, low-level microdynamics of local interaction between elements; and how exactly is the holistic phenomenology of bodily self-consciousness grounded in second-order embodiment? As indicated above, my own recommendation would be not to throw the baby out with the bathwater, but to mathematically describe “representationality” as a property that is graded, allowing the PSM to naturally “bottom out” into non-representational dynamics. The best indicator of progress will be the disappearance of Yes-or-No answers to questions like “Is bodily self-consciousness representational or not?” or “Is 3E possible in the absence of 2E?” These questions themselves are misleading.

One background assumption behind the conceptual distinction I have offered is that an ordinary human being, inattentively walking along the street “on autopilot,” clearly exhibits 1E and 2E all of the time, whereas 3E is a fluctuating property, coming in different degrees and strengths. To be sure, we use physical properties of our bodies when generating the controlled

form of falling we call “walking,” and certainly there is an unconscious body schema supporting us when we walk through the street with a wandering mind (e.g. Haggard and Wolpert, 2005; Schilling and Cruse, 2012; Metzinger, 2013c). But if we take our own body phenomenology seriously, we rarely have the body as a whole, it is more like “body islands” emerging and capturing our attention – an itch, a sudden sense of effort, a short loss of balance (e.g. Smith, 2009, pp. 89–90). There is a constant sense of identification with the body, but the actual conscious content is highly variable, task- and context-dependent. For a Zen monk walking extremely slowly and mindfully, say, during the practice of *kinhin* (walking) meditation, the phenomenological profile may be very different. Perhaps 3E is strongly expressed in terms of a dynamically stable, globally integrated body phenomenology, perhaps 3E is completely absent, because identification has been shifted to the situation model as a whole, or to the unity of consciousness as such.

Example 2: full-body illusions and the concept of “minimal phenomenal selfhood”

What is the absolutely essential, the most central grounding relation that we find in *all* those cases where a system exhibits 1E, 2E, and 3E at the same time? Clearly, there will be no single, universal answer to this question: Bodily self-awareness will be extremely different in different types of systems (say, robots instantiating synthetic phenomenology, or dolphins, or humans), and the specific grounding relations for their respective PSMs will vary greatly (Shapiro, 2012, p. 143). Again, the search for an “essence” may be misguided. If we limit our intended class of systems to human beings in non-pathological waking states, then the question becomes: Is there a simplest, absolutely minimal form of self-consciousness, a fundamental form of phenomenal selfhood that underlies all other configurations and kinds of grounding? To answer this question we need to isolate the domain-specific, minimal form of phenomenal selfhood. For example, we might ask: Can there be conscious body representation without *own*-body representation – that is, bodily awareness without the phenomenology of ownership and bodily selfhood (Martin, 1995, pp. 269–70)? Can the two components of selfhood and body representation be functionally dissociated? This leads to the question of “minimal phenomenal selfhood” (Blanke and Metzinger, 2009). MPS is a new research target, namely, the attempt to isolate the minimal conditions for self-consciousness to appear in a given class of information-processing systems.

One important distinction is the one between local and global ownership (Blanke and Metzinger, 2009, p. 9; Petkova *et al.*, 2011). For example, in a disorder that has been called somatoparaphrenia, the phenomenology of ownership for a body part may break down following damage to right temporoparietal cortex (Vallar and Ronchi, 2009). Somatoparaphrenic patients most often misattribute their contralesional hand as belonging to another mostly familiar person such as their doctor, nurse, a hospital neighbor, or friend. Other somatoparaphrenic patients suffer from the opposite pattern and self-attribute other people’s hands when these are presented in their contralesional hemispace. Somatoparaphrenia affects only the contralesional (mostly left) hand (or foot) and never ipsilesional body parts. Somatoparaphrenia must be distinguished from other bodily symptoms reflecting disturbed partial ownership and/or agency such as xenomelia (the oppressive feeling that one or more limbs of one’s body do not belong to one’s self, sometimes also termed “body integrity identity disorder”; see e.g. Hilti *et al.*, 2013), anosognosia for a paralyzed limb, asomatognosia, alien hand syndrome, or supernumerary phantom limbs. We must do justice to the fact that a complex set of phenomenological constraints has to be satisfied by any convincing theory, since there is a high-dimensional, variable landscape in bodily self-consciousness. This implies that phenomenological aspects like “identification” and “ownership” cannot be captured by a simple global/local distinction, but have to be described

in their fine-grained variance (Longo, Schüür, Kammers, Tsakiris, and Haggard, 2008; Tsakiris, 2010; Longo and Haggard, 2012).

Global aspects of 3E as well as unconscious mechanisms of spatial self-location can be manipulated in a predictable fashion. In a now classic study (Lenggenhager, Tadi, Metzinger, and Blanke, 2007), a protocol similar to that in the rubber-hand illusion (RHI; Botvinick and Cohen, 1998) was extended to the full body, inducing FBIs. A video camera with a 3D-encoder was placed behind the subject and relayed to a head mounted display. Tactile stimulation (stroking) was applied on the back and the visual information related to this stimulation was systematically manipulated by displaying it either synchronously or asynchronously with the tactile sensation. Under these conditions, two measures were acquired: questionnaire scores to quantify self-identification and drift to quantify self-location. When the participants saw their body in front of themselves, being stroked synchronously on their own back, they sometimes felt as if the virtual body was their own (illusory self-identification) and showed drift towards it (illusory self-location). Both FBI-measures were also observed for a fake body, but not, or to a weaker degree, for a rectangular object. The FBI (which generally is a weaker effect than the RHI) was abolished during asynchronous stroking. Henrik Ehrsson (2007) used a similar set-up, but stroked subjects on their chests (hidden from the view of the camera). In this FBI version, subjects saw the synchronous stroking in front of the camera, inducing the experience of being at the position of the camera that was behind the subjects' body. Research on FBIs, virtual and robotic re-embodiment is now a burgeoning interdisciplinary field of research in which new experimental techniques like the combination of virtual reality and fMRI are explored (see Blanke, 2012, for review). For the self grounding problem, all these new data may turn out to be decisive, because they demonstrate how the target property of phenomenal selfhood can in principle be grounded via the agency-independent property of passive body identification, which in turn can be selectively controlled and experimentally manipulated. What we currently lack is an adequate computational model *specifying* the grounding relations between 3E, 2E, and 1E.

MPS can be analyzed on phenomenological, representational, and functional levels of description. Central defining features are (1) a globalized form of identification with the body as a whole (as opposed to ownership for body parts), (2) spatio-temporal self-location, and (3) a first-person perspective (1PP). It is important to differentiate between a weak and at least two stronger readings of 1PP. MPS is the central enabling condition on the weak reading; it is a necessary (but not sufficient) condition on both stronger readings. A weak 1PP is a purely geometrical feature of a perceptual or imagined model of reality and has formed the target of empirical studies investigating visuospatial perspective-taking (Pfeiffer *et al.*, 2013). For example, in the human case a unimodal (e.g. visual) weak 1PP typically includes a spatial frame of reference, plus a global body representation, with a perspective originating *within* this body representation. There exists a center of projection, which functions as the geometrical origin of the "seeing" organism's passive perspective. Another important example is the sense of balance automatically provided by the vestibular system, whereas the sense of smell arguably may already present us with an intrinsically active modality, because the conscious detection of odorants involves top-down attention, however minimal. This is not to be confused with the warning system of the trigeminal nerve in the nasal cavity. The conscious experience of smells as perceived without being attended to are likely to be mediated by this warning system and not by the olfactory system (see Keller, 2011, p. 10). One conceptual difficulty here is that in *multimodal* experience "egocentric space seems unified in ways that resist neat characterization in terms of a privileged point of origin" (Smith, 2010, pp. 37, 39).

A stronger 1PP appears when the system as a whole is internally represented and actively *directed* at an object component, for example a perceptual object, an action goal, or perhaps the

body as a whole. Conscious robots or other artificial systems might gradually develop their own kind of perspectivalness (Kuniyoshi *et al.*, 2007), but in human beings, we find the attentional 1PP and the cognitive 1PP. The property of “visual attentional agency” provided above is a good example, because the strong 1PP often involves the additional experience of controlling the focus of attention. From a philosophical perspective, attentional agency is one of the most interesting properties of all, because it marks the transition from passive identification with a body image to the stronger sense of selfhood generated in the process of active self-control. A strong 1PP is exactly what makes consciousness *subjective*: the fact that a system represents itself not only as a self, but as an epistemic agent. The capacity to represent oneself as an entity that actively seeks knowledge and is dynamically directed at *epistemic* goal states is, of course, not confined to the visual modality – a subjective perspective can also involve the sense of smell, auditory experience, or the introspective, inward-directed exploration of proprioception, of interoceptive feelings, or emotional states. Importantly, this also means that the organism represents itself *as representing*, because it co-represents the representational relation during the ongoing process of representation: a phenomenal self *as subject* appears exactly when the organism possesses a phenomenal model of the intentionality relation (Metzinger, 2003a, 2007). Perhaps there is an even stronger 1PP, which implies the possession of the *concept* of a subject of experience (an abstract “amodal self symbol”), and the additional ability of a given system to mentally apply this concept to itself. Such a “cognitive 1PP” is something I will not discuss here, because at present it is mostly of interest to philosophers and still outside the scope of empirical research programs.

Having MPS is a necessary condition for the strong (i.e. attentional and/or cognitive) 1PP, but not for the weak 1PP, because the weak 1PP is itself a constituting factor for MPS. The notion of “embodiment” is of central relevance for MPS and finding out how critical global bodily properties like self-identification, self-location, and 1PP can be grounded and functionally anchored in the brain. In standard configurations, the conscious body model defines a volume within a spatial frame of reference (the dimension of “self-location”) within which the origin of the weak 1PP is also localized. Self-location possesses a variable internal structure: the bodily self is phenomenally represented as inhabiting a *volume* in space, whereas the weak 1PP is projected from an extensionless point, the geometrical origin of our perspectival visual model of reality (remember the example of visual attentional agency during some lucid dreams or asomatic OBEs). Normally this point of origin is embedded *within* the volume defined by self-location. Because this conscious body model is transparent, that is, because it cannot introspectively be recognized *as* a model, we fully identify with its representational content and enjoy the phenomenology of presence as bodily selves. But as we have seen above, it may be possible to *integrate* conditions (1) and (2), because more recent research has demonstrated the high prevalence of asomatic OBEs and dreams in which the sense of selfhood remains stable. MPS could then be transparent self-location in a spatio-temporal frame of reference (Windt, 2010).

In ordinary wake states, and on the representationalist level of description, the content of MPS has the function of indicating that a specific state in the system’s internal neural dynamics has been reached, namely an integrated functional state that makes the body available for attention and global control. MPS, characterized by self-identification, self-location, and the weak 1PP, is the conscious representation of this achievement – and it is exactly the property that emerges when we wake up in the morning, when we suddenly “come to” ourselves. The simplest form of selfhood is a representation not of ongoing motor behavior or perceptual and attentional processing directed at single body parts, but of the entire body as being *functionally available* for global control. MPS thereby is a form of abstract (yet non-propositional) knowledge about oneself, information about newly acquired causal properties.

How can MPS be grounded with the help of a computational model? One might argue that MPS appears if and only if an organism has made such global properties of its own body available for flexible, high-level control and represents this very fact to itself. It is also important to understand that MPS as well as more complex forms of self-representation are not static internal copies of some mysterious thing or individual substance (“the” self), but only ongoing processes of tracking and controlling global bodily properties – for example with the help of an explicit, integrated body model. “Global control” is a process in which a system controls global properties of itself (as opposed to local properties). A global property is one that can only meaningfully be ascribed to a given system as a whole, often because it requires a new level of analysis defined by a different logical subject plus a corresponding set of predicates. A drop of water is wet, but none of the individual H₂O molecules has the property of “wetness.” Global properties of the human body are for example the specific shape of the entire body surface or the whole body’s translational properties as opposed to partial properties such as the skin of the fingertip or hand translation. The possession of MPS, of a weak, strong, or even cognitive 1PP, is also the possession of global properties; no individual part can have them. Third-order embodiment and self-consciousness more generally are properties of the system as a whole.

In conclusion, the self grounding problem can be viewed as an interesting set of conceptual and empirical issues that we discover when looking at a certain kind of system from the outside, from a third-person perspective, and with the eyes of a philosopher or scientist. It can be solved by formally specifying the grounding relations that hold between constitutive elements on different levels of embodiment, for example by describing degrees of representationality, local neural correlates (for phenomenal properties), or more extended dynamic interactions (for semantic properties). However, it is at least equally interesting to note how the solution to this problem can also be viewed from the perspective of the continuously evolving individual system itself, namely, as the acquisition of an extremely relevant set of *functional properties*: it is one thing to develop an explicit body model, eventually leading to a PSM, but it is quite another to reliably ground it in the process of controlling a real, physical body and to successfully embed it in a dense mesh of successful interactions – not only with the current situation, but also in the context of internally generated virtual environments and extended social ontologies. Passive identification through MPS is not the same as active body ownership via situated global self-control. Third-order embodiment and PSM have to become *functionally adequate* aspects of a much larger process. Any system that has achieved this to a sufficiently high degree has individually solved the self-grounding problem (now spelled with a hyphen), because it has grounded *itself* in a new way, by ascending to higher levels of embodiment. Perhaps future research can even interestingly connect such higher levels of embodiment with traditional philosophical notions like “autonomy.”

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Notes

- 1 I first introduced these three concepts in Metzinger (2006). The concept of MPS was first developed in Blanke and Metzinger, 2009; references for the notion of a phenomenal self-model (PSM) are given in the main text.

- 2 It is interesting to note how this fact is highly relevant for ethics, because it is the central necessary precondition for the capacity to suffer, and it is specified in a hardware-independent way. Therefore, 3E plus valence representation helps us to define the class of objects of ethical consideration, for example in robot ethics (cf. Metzinger, 2013a, p. 262)
- 3 The phenomenon of heautoscopy provides an interesting (but rare) example of a specific neurological disorder in which patients see a hallucinatory image of their *own* body in extracorporeal space, with the phenomenal “locus of identification” being ambiguous. Specifically, the patient’s stable, subjective sense of being anchored in one single body dissolves into a feeling of bi-location or of jumping back and forth between two body representations (see figure 1 and box 2 in Blanke and Metzinger, 2009, p. 10). This demonstrates how the identification component and the self-location component in 3E can be selectively compromised in *non-social configurations*, with the only additional body model available on the level of conscious experience being a hallucinatory model of the patient’s *own* body as visually perceived. Heautoscopy is also associated with depersonalization and vestibular disorders (see Heydrich and Blanke, 2013). Out-of-body experiences are an obvious example for a second relevant class of 3E states frequently occurring in the absence of any social situation or context. See Blanke and Mohr, 2005, and Blanke, 2012, for review and further references.
- 4 Introducing this conceptual distinction enables us to ask new research questions more precisely, by drawing attention to the logical possibility of conscious systems not exhibiting 3E: Could there be conscious systems that (a) lack any conscious body model whatsoever, or (b) systems that possess body phenomenology, but selectively lack the passive sense of identification? Simple biological organisms, or patients suffering from severe cases of depersonalization disorder or Cotard syndrome, might be examples of such phenomenal state classes.
- 5 Here, the concept of “global availability” functions as a placeholder for “conscious processing”; see Metzinger, 2003a, pp. 30 and 117, for details and additional constraints.
- 6 See Metzinger, 2013b, for details. Empirical studies on so-called “asomatic” OBEs seem to show that not only are about 29 percent of OBEs characterized by an indefinite spatial volume of the body, but that another 31 percent seem to be “bodiless” altogether – while preserving a stable sense of selfhood – because they are experienced as bodiless and include an externalized visuospatial perspective only (e.g. Wolfradt, 2000). In dream research we find similar data showing how spatial self-location can be independent of bodily experience (though it will still involve the experience of being an extensionless point in space; cf. Windt, 2010). For reports of phenomenal selfhood lacking the phenomenology of embodiment, see Occhionero, Cicogna, Natale, Esposito, and Bosinelli, 2005; LaBerge and DeGracia, 2000; for a philosophical discussion of such experiences in dreams, see Windt, 2010, in press.
- 7 One of the weaknesses of supervenience theory generally speaking is that it is a *non-explanatory relationship*, because ultimately it does not tell us anything about the inner nature of psychophysical correlations. However, for every *local* supervenience relation that allows us to understand how supervenient causation is possible, there will be a nomologically equivalent, coextensive base property relative to the specific physical system we are looking at – and nomological coextensionality is an identity condition for properties. So local grounding will eventually go along with either a domain-specific reductive explanation or an elimination of phenomenal target properties like “selfhood” or “identification.” See Kim, 1989, n. 29.

References

- Alsmith, A. J., and de Vignemont, F. (2012). Embodying the mind and representing the body. *Review of Philosophy and Psychology*, 3(1), 1–13.
- Ay, N., and Zahedi, K. (2013). Causal effects for prediction and deliberative decision making of embodied systems. In Y. Yamaguchi (Ed.), *Advances in Cognitive Neurodynamics: Vol. 3. Proceedings of the Third International Conference on Cognitive Neurodynamics – 2011* (pp. 499–506). Heidelberg: Springer.
- Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, 59, 617–45.
- Blanke, O. (2012). Multisensory brain mechanisms of bodily self-consciousness. *Nature Reviews Neuroscience*, 13(8), 556–71.
- Blanke, O., and Metzinger, T. (2009). Full-body illusions and minimal phenomenal selfhood. *Trends in Cognitive Sciences*, 13(1), 7–13.
- Blanke, O., and Mohr, C. (2005). Out-of-body experience, heautoscopy, hallucination of neurological and autoscopic origin implications for neurocognitive mechanisms of corporeal awareness and self-consciousness. *Brain Research Reviews*, 50(1), 184–99.

- Bongard, J., Zykov, V., and Lipson, H. (2006). Resilient machines through continuous self-modeling. *Science*, 314(5802), 1118–21.
- Botvinick, M., and Cohen, J. (1998). Rubber hands “feel” touch that eyes see. *Nature*, 391(6669), 756.
- Brooks, R. A. (1991). Intelligence without representation. *Artificial Intelligence*, 47(1–3), 139–59.
- Chemero, A. (2009). *Radical embodied cognitive science*. Cambridge, MA: MIT Press.
- Cheyne, J. A. (2003). Sleep paralysis and the structure of waking-nightmare hallucinations. *Dreaming*, 13, 163–79.
- (2005). Sleep paralysis episode frequency and number, types, and structure of associated hallucinations. *Journal of Sleep Research*, 14, 319–24.
- Cheyne, J. A., Rueffer, S. D., and Newby-Clark, I. R. (1999). Hypnagogic and hypnopompic hallucinations during sleep paralysis: Neurological and cultural construction of the night-mare. *Consciousness and Cognition*, 8, 319–37.
- Clark, A. (1993). *Microcognition: Philosophy, cognitive science, and parallel distributed processing* (4th ed.). Cambridge, MA: MIT Press.
- Cruse, H., and Steinkühler, U. (1993). Solution of the direct and inverse kinematic problems by a common algorithm based on the mean of multiple computations. *Biological Cybernetics*, 69(4), 345–51.
- Cruse, H., Steinkühler, U., and Burkamp, C. (1998). MMC – A recurrent neural network which can be used as manipulable body model. In *From Animals to Animats 5: Proceedings of the Fifth International Conference on Simulation of Adaptive Behavior* (pp. 381–89). Cambridge, MA: MIT Press.
- Dang-Vu, T. T., Desseilles, M., Albouy, G., Darsand, A., Gals, S., Rauchs, G., Schabus, M., Sterpenich, V., Vandewalle, G., Schwartz, S., and Maquet, P. (2005). Dreaming: A neuroimaging view. *Swiss Archives of Neurology and Psychiatry*, 156, 415–25.
- Dang-Vu, T. T., Desseilles, M., Petit, D., Mazza, S., Montplaisir, J., and Maquet, P. (2007). Neuroimaging in sleep medicine. *Sleep Medicine*, 8(4), 349–72.
- Dement, W. C., and Wolpert, E. (1958). The relation of eye movements, body motility, and external stimuli to dream content. *Journal of Experimental Psychology*, 55, 543–53.
- de Vignemont, F. (2010). Body schema and body image – Pros and cons. *Neuropsychologia*, 48(3), 669–80.
- Dresler, M., Wehrle, R., Spoormaker, V. I., Koch, S. P., Holsboer, F., Steiger, A., et al. (2012). Neural correlates of dream lucidity obtained from contrasting lucid versus non-lucid REM sleep: A combined EEG/fMRI CASE Study. *Sleep*, 35(7), 1017–20.
- Ehrsson, H. H. (2007). The experimental induction of out-of-body experiences. *Science*, 317(5841), 1048.
- Fenwick, P., Schatzman, M., Worsley, A., Adams, J., Stone, S., and Baker, A. (1984). Lucid dreaming: Correspondence between dreamed and actual events in one subject during REM sleep. *Biological Psychology*, 18, 243–52.
- Freud, S. (1899/2003). *Die Traumdeutung*. Frankfurt am Main: Fischer Taschenbuch.
- Gallagher, S. (2005). *How the Body Shapes the Mind* (Oxford Scholarship Online). Oxford: Oxford University Press.
- Gloye, A., Wiesel, F., Tenchio, O., and Simon, M. (2005). Verbesserung der Fahreigenschaften von fußballspielenden Robotern durch Antizipation [Reinforcing the driving quality of soccer playing robots by anticipation]. *IT – Information Technology*, 47(5), 250–57.
- Haggard, P., and Wolpert, D. M. (2005). Disorders of body scheme. In H. J. Freund, M. Jeannerod, M. Hallett, and R. Leiguarda (Eds.), *Higher-order motor disorders*. Oxford: Oxford University Press.
- Harnad, S. (1990). The symbol grounding problem. *Physica D: Nonlinear Phenomena*, 42(1–3), 335–46.
- Heydrich, L., and Blanke, O. (2013). Distinct illusory own-body perceptions caused by damage to posterior insula and extrastriate cortex. *Brain*, 136(3), 790–803.
- Hilti, L. M., Hänggi, J., Vitacco, D. A., Kraemer, B., Palla, A., Luechinger, R., et al. (2013). The desire for healthy limb amputation: Structural brain correlates and clinical features of xenomelia. *Brain* 136(1), 318–29.
- Hobson, J. A., Pace-Schott, E. F., and Stickgold, R. (2000). Dreaming and the brain: Toward a cognitive neuroscience of conscious states. *Behavioral and Brain Sciences*, 23(6), 793–842.
- Hoff, H. (1929). Zusammenhang von Vestibularfunktion, Schlafstellung und Traumleben. *Monatsschrift für Psychiatrie und Neurologie*, 71(5–6), 366–72.
- Hoff, H., and Plötzl, O. (1937). Über die labyrinthären Beziehungen von Flugsensationen und Flugträumen. *Monatsschrift für Psychiatrie und Neurologie*, 97(4), 193–211.
- Hoffmann, M., Marques, H. G., Hernandez Arieta, A., Sumioka, H., Lungarella, M., and Pfeifer, R. (2010). Body schema in robotics: A review. *IEEE Transactions on Autonomous Mental Development*, 2(4), 304–24.
- Keller, A. (2011). Attention and olfactory consciousness. *Frontiers in Psychology*, 2(380), 1–12.

- Kim, J. (1989). The myth of nonreductive materialism. *Proceedings and Addresses of the American Philosophical Association*, 3, 31–47.
- Koulack, D. (1969). Effects of somatosensory stimulation on dream content. *Archives of General Psychiatry*, 20(6), 718–25.
- Kuniyoshi, Y., Yorozu, Y., Suzuki, S., Sangawa, S., Ohmura, Y., Terada, K., et al. (2007). Emergence and development of embodied cognition: A constructivist approach using robots. *Progress in Brain Research*, 164, 425–56.
- LaBerge, S., and DeGracia, D. J. (2000). Varieties of lucid dreaming experience. In R. G. Kunzendorf and G. Wallace (Eds.), *Individual differences in conscious experience* (pp. 269–307), Amsterdam: John Benjamins.
- LaBerge, S., and Dement, W. C. (1982). Voluntary control of respiration during lucid REM dreaming. *Sleep Research*, 11, 107.
- LaBerge, S., Greenleaf, W., and Kedzierski, B. (1983). Physiological responses to dreamed sexual activity during REM sleep. *Psychophysiology*, 19, 454–55.
- LaBerge, S., Stephen, P., Nagel, L. E., Dement, W. C., and Zarcone, V. P. (1981). Lucid dreaming verified by volitional communication during REM sleep. *Perceptual and Motor Skills*, 52, 727–32.
- Lenggenhager, B., Tadi, T., Metzinger, T., and Blanke, O. (2007). Video ergo sum: Manipulating bodily self-consciousness. *Science* 317(5841), 1096–99.
- Leslie, K., and Ogilvie, R. D. (1996). Vestibular dreams: the effect of rocking on dream mentation. *Dreaming*, 6(1), 1–16.
- Longo, M. R., and Haggard, P. (2012). What is it like to have a body? *Current Directions in Psychological Science*, 21(2), 140–45.
- Longo, M. R., Schüür, F., Kammers, M. P., Tsakiris M., and Haggard, P. (2008). What is embodiment? A psychometric approach. *Cognition*, 107(3), 978–98.
- Maravita, A., Spence, C., and Driver, J. (2003). Multisensory integration and the body schema: Close to hand and within reach. *Current Biology*, 13(13), R531–39.
- Martin, M. G. (1995). Bodily awareness: A sense of ownership. In J. L. Bermúdez, and A. J. Marcel (Eds.), *The body and the self* (pp. 267–89). Cambridge, MA: MIT Press.
- Metzinger, T. (1995). *Conscious experience*. Exeter: Imprint Academic.
- (2000). *Neural correlates of consciousness: Empirical and conceptual questions*. Cambridge, MA: MIT Press.
- (2003a). *Being no one: The self-model theory of subjectivity*. Cambridge, MA: MIT Press.
- (2003b). “Phenomenal transparency and cognitive self-reference. *Phenomenology and the Cognitive Sciences*, 2(4), 353–93.
- (2006). Different conceptions of embodiment. *Psyche*, 12(4), 1–7. Retrieved from http://www.philosophie.uni-mainz.de/Dateien/Metzinger_PSYCHE_2006.zip
- (2007). Self models. *Scholarpedia*, 2(10), 4174.
- (2009). Why are out-of-body experiences interesting for philosophers? *Cortex*, 45(2), 256–58.
- (2010). *The EGO tunnel: The science of the mind and the myth of the self* (1st ed.). New York: Basic Books.
- (2013a). Two principles for robot ethics. In E. Hilgendorf and J.-P. Günther (Eds.), *Robotik und Gesetzgebung*. Baden-Baden: Nomos.
- (2013b). Why are dreams interesting for philosophers? The example of minimal phenomenal selfhood, plus an agenda for future research. *Frontiers in Psychology*, 4(746).
- (2013c). The myth of cognitive agency: Subpersonal thinking as a cyclically recurring loss of mental autonomy. *Frontiers in Psychology*, 4(931).
- Metzinger, T., and Gallese, V. (2003). The emergence of a shared action ontology: Building blocks for a theory. *Consciousness and Cognition*, 12(4), 549–71.
- Nielsen, T. A. (1993). Changes in kinesthetic content of dreams following somatosensory stimulation of leg during REM sleep. *Dreaming*, 3, 99–113.
- Nielsen, T. A., Ouellet, L., and Zadra, A. L. (1995). Pressure stimulation during REM sleep alters dream limb activity and body bizarreness. *Sleep Research*, 24, 134.
- Nielsen, T. A., Svob, C., and Kuiken, D. (2009). Dream-enacting behaviors in a normal population. *Sleep*, 32(12), 1629–36.
- Occhionero, M., Cicogna, P., Natale, V., Esposito, M. J., and Bosinelli, M. (2005). Representation of self in SWS and REM dreams. *Sleep and Hypnosis*, 7(2), 77–83.
- Petkova, V. I., Björnsdotter, M., Gentile, G., Jonsson, T., Li, T. Q., and Ehrsson, H. H. (2011). From part- to whole-body ownership in the multisensory brain. *Current Biology*, 21(13), 1118–22.

- Pezzulo, G., Barsalou, L. W., Cangelosi, A., Fischer, M. H., McRae, K., and Spivey, M. J. (2013). Computational grounded cognition: A new alliance between grounded cognition and computational modelling. *Frontiers in Psychology*, 3(612).
- Pfeiffer, C., Lopez, C., Schmutz, V., Duenas, J. A., Martuzzi, R., and Blanke, O. (2013). Multisensory origin of the subjective first-person perspective: Visual, tactile, and vestibular mechanisms. *PLoS One*, 8(4), e61751.
- Sauvageau, A., Nielsen, T. A., and Montplaisir, J. (1998). Effects of somatosensory stimulation on dream content in gymnasts and control participants: Evidence of vestibulomotor adaptation in REM sleep. *Dreaming*, 8, 125–34.
- Sauvageau, A., Nielsen, T. A., Ouellet, L., and Montplaisir, J. (1993). Eye movement density and amplitude after somatosensory stimulation during REM sleep: Effects on gymnasts and controls. *Sleep Research*, 22, 133.
- Schenck, C. (2005). *Paradox lost: Midnight in the battleground of sleep and dreams*. Minneapolis, MN: Extreme Nights, LLC.
- (2007). *Sleep: The mysteries, the problems, and the solutions*, New York: Avery.
- Schilling, M., and Cruse, H. (2012). What's next: Recruitment of a grounded predictive body model for planning a robot's actions. *Frontiers in Psychology*, 3(383).
- Schmidhuber, J. (2007). Prototype resilient, self-modeling robots. *Science*, 316(5825), 688c.
- Schönhammer, R. (2004). *Fliegen, Fallen, Flüchten: Psychologie intensiver Träume*. Tübingen: dgvt.
- (2005). "Typical dreams": Reflections of arousal. *Journal of Consciousness Studies*, 12(4–5), 18–37.
- Schredl, M., and Erlacher, D. (2008). Do REM (lucid) dreamed and executed actions share the same neural substrate? *International Journal of Dream Research*, 1(1), 7–14.
- Seth, A. K. (2013). Interoceptive inference, emotion, and the embodied self. *Trends in Cognitive Sciences*, 17(11), 565–73.
- Seth, A. K., Suzuki, K., and Critchley, H. D. (2012). An interoceptive predictive coding model of conscious presence. *Frontiers in Psychology*, 2(395).
- Shapiro, L. A. (2012). Embodied cognition. In E. Margolis, R. Samuels, and S. Stich (Eds.), *The Oxford handbook of philosophy of cognitive science*. Oxford: Oxford University Press.
- Smith, A. J. T. (2009). Acting on (bodily) experience. *Psyche*, 15(1), 82–99. Retrieved from <http://www.theassc.org/files/assc/2581.pdf>
- (2010). Comment: Minimal conditions for the simplest form of self-consciousness. F. Fuchs, H. C. Sattel, and P. Hennington (Eds.), *The embodied self: Dimensions, coherence and disorders* (pp. 35–42). Stuttgart: Schattauer.
- Tsakiris, M. (2010). My body in the brain: A neurocognitive model of body-ownership. *Neuropsychologia*, 48(3), 703–12.
- Vallar, G., and Ronchi, R. (2009). Somatoparaphrenia: A body delusion – A review of the neuropsychological literature. *Experimental Brain Research*, 192(3), 533–51.
- Voss, U., Holzmann, R., Tuin, I., and Hobson, J. A. (2009). Lucid dreaming: A state of consciousness with features of both waking and non-lucid dreaming. *Sleep*, 32(9), 1191–1200.
- Voss, U., Schermelleh-Engel, K., Windt, J., Frenzel, C., and Hobson, A. (2013). Measuring consciousness in dreams: The lucidity and consciousness in dreams scale. *Consciousness and Cognition*, 22(1), 8–21.
- Weber, A. M., and Vosgerau, G. (2012). Grounding action representations. *Review of Philosophy and Psychology*, 3(1), 53–69.
- Wilson, A. D., and Golonka, S. (2013). Embodied cognition is not what you think it is. *Frontiers in Psychology*, 4(58).
- Windt, J. M. (2010). The immersive spatiotemporal hallucination model of dreaming. *Phenomenology and the Cognitive Sciences*, 9(2), 295–316.
- (in press). *Dreaming: A conceptual framework for philosophy of mind and empirical research*. Cambridge, MA: MIT Press.
- Windt, J. M., and Metzinger, T. (2007). The philosophy of dreaming and self-consciousness: What happens to the experiential subject during the dream state? In D. Barrett and P. McNamara (Eds.), *The new science of dreaming: Vol. 3. Cultural and theoretical perspectives* (pp. 193–247) (Praeger Perspectives). Westport, CT: Praeger Publishers; Greenwood Publishing Group.
- Wolfradt, U. (2000). Außerkörpererfahrungen (AKE) aus differentiell-psychologischer Perspektive. *Zeitschrift für Parapsychologie und Grenzgebiete der Psychologie*, 1(42–43), 65–108.
- Yamaguchi, Y. (Ed.) (2013). *Advances in Cognitive Neurodynamics: Vol. 3. Proceedings of the Third International Conference on Cognitive Neurodynamics – 2011*. Heidelberg: Springer.
- Zahedi, K., Ay, N., and Der, R. (2010). Higher coordination with less control – A result of information maximization in the sensorimotor loop. *Adaptive Behavior*, 18(3–4), 338–55.

ACTING FOR BODILY AWARENESS

Frédérique de Vignemont

For almost thirty years now, the growing program of embodied cognition has tried to elevate the importance of the body in explaining cognitive activities. Embodied theorists claim that the body has a crucial significance in how and what the organism thinks and feels. Paradoxically, most of the time there is no description of bodily experiences in embodied theories, with few exceptions (e.g. Gallagher, 2005). While putting so much emphasis on the role of the body for many cognitive functions, embodied theorists tend to neglect the body for its own sake. Part of the reasons for this neglect is that the body is the *explanans*, not the *explanandum*. But one cannot ground cognition in the body if one has no understanding of what it means to have a body. In this sense, it is important to step back from speculations about the possible roles of the body for the mind and to start at the very beginning by asking the following question: How does one experience one's body? One may then wonder whether one can give an embodied account of bodily awareness that does not fall into triviality (bodily awareness explained by the body), namely, a sensorimotor account. But to what extent and in what manner can action account for bodily awareness?

The space of the body

According to Merleau-Ponty, bodily space is a space of action. The action needs not be performed, but can remain virtual. In his words, the lived body consists in an "I can" (1945, p. 137). For instance, he claims that phantom limbs are merely the consequence of the preserved readiness to move the amputated limbs. More generally, Merleau-Ponty argues in favor of the constitutive role of action for consciousness. As such, he can be considered as one of the ancestors of the recent enactive view, which claims that conscious experiences are inseparable from bodily activities (Siewert, 2005; O'Regan and Noë, 2001; O'Regan, 2011; Noë, 2004; Hurley, 1998; Thompson, 2005). On this view, what we feel is determined by what we do and what we know how to do. Proponents of the enactive view thus argue for a relation of constitutive interdependence between perception and action. Perception is not merely a means to action and action a means to perception. Instead, perceptual content, especially in the perception of spatial properties, constitutively depends on law-like relationships that hold between sensory input and

motor output. Perceptual experiences are thus said to be inseparable from the perceiver's bodily activities. Although it is vision that has received the most attention, the enactive view has been generalized to other perceptual experiences, including bodily experiences:

For example, when something tickles you on your arm, you can move your other hand and scratch the tickled location ... What we mean by feeling something in a particular place in our bodies is precisely that certain sensorimotor laws apply.

(O'Regan, 2011, pp. 157–58)

However, the enactive view of bodily experiences raises empirical and conceptual worries (for further details see de Vignemont, 2011). The first difficulty arises from the existence of double dissociations between bodily know-how (i.e. how to reach the bodily location that was touched and how to move it) and bodily awareness. If bodily awareness consisted in bodily know-how, then one could not have one without the other. Yet, it has been recently found that the possession of accurate bodily know-how does not guarantee that one consciously feels touch or feels where the touch occurs. For instance, patients with numbsense have no tactile awareness, but retain a surprising ability to point to where they were touched: “But, I don’t understand that. You put something there; I do not feel anything and yet I got there with my finger. How does that happen?” (in Paillard, Michel, and Stelmach, 1983, p. 550). A further dissociation can be found in two patients, KE and JO, who can both consciously feel a touch (Anema *et al.*, 2009). Surprisingly, JO can indicate on her hand where she was touched, but not on a pictorial representation of her hand. By contrast, KE can localize the tactile stimulus on the hand drawing, but not on his own hand. Although he knows where he was touched, he is unable to get to the right location of the touch on his hand. This latter case is especially interesting because it shows that bodily know-how is not a necessary condition for experiencing touch on one’s hand.

The second difficulty that the enactive view faces is conceptual. In a nutshell, action cannot account for bodily experiences, because they do not take place in the same spatial frame of reference. Let us consider the following example. A spider lands on the back of my right hand. It tickles me. According to the enactive view, my ticklish sensation consists in the expectation that I can move my other hand and remove what is tickling me. I then wave my hand hoping that the spider will fall, but I fail. All through my movement, I still feel the sensation on my right hand. I experience my hand moving but I do not experience my sensation moving. Yet, the specific bodily movement for my left hand to reach my right hand has changed. One may then conclude that the tactile-motor law has changed, although the localization of my ticklish sensation has not. Consequently, according to the enactive view, the localization of my bodily experience should have moved. Since it has not moved, feeling sensation in a particular body part does not consist in such sensorimotor laws.

A proponent of the enactive view might agree and claim that the tactile-motor law is only the general fact that reaching the hand that is touched with the other hand will stop the tactile signal, no matter the specific trajectory between the two hands. But even then it is not certain that one gains a clear understanding of the bodily location. One may say that sensorimotor laws are body-part specific, and as such provide the bodily location. It is only if I reach my right hand, and not any other body part, and remove the spider on it that I can expect the tactile signal to stop. But how do I know that it is my right hand that must be the target of my movement? In order to act upon a body part, one needs first to be able to single it out, and this cannot be done on the basis of sensorimotor laws for threat of circularity. One needs a prior and independent way of singling out the relevant body part that is in contact with the object in order to avoid a circular account of bodily experiences.

Rather than enactivism, I defend a representationalist approach to bodily awareness. On this view, phantom limbs do not reveal a preserved readiness to move. Actually most patients feel that they cannot move their phantom limbs. Rather, as noted by Schilder (1935), phantom limbs are the clearest pathological expression of the existence of the representation of the body in the mind. Patients can feel sensations in a limb that no longer exists thanks to the body representation that still includes the amputated limb. The body senses, including the sense of pressure, the sense of posture and the sense of balance, do not directly carry information about the shape of the various parts of the body, their spatial configuration and their size. In order to compensate for their insufficiencies, bodily information needs to be spatially organized by a representation of the configuration and metrics of the body segments, what I call a *body map*. It is thanks to the body map that sensations are experienced as being at more than an isolated body point. The body map gives a spatial frame of reference to bodily experiences. In visual experiences, visual properties are ascribed to specific locations within the visual field. In bodily experiences, bodily properties are ascribed to specific locations within the body map. The body map is the background on which bodily sensations are experienced. Thanks to the body map, all bodily experiences over an extended period share the same spatial content of the structural shape of the body (O'Shaughnessy, 1980).

The body map thus accounts for the spatiality of bodily experiences in association with spatial information carried by body senses. But what are the origin and the format of the body map? Action may then come back by a side door by shaping the body map.¹ For example, we know that young infants engage in repetitive actions on their own body and explore visual-proprioceptive correspondence (Morgan and Rochat, 1997). Later on, one can gain knowledge about the size of one's limbs thanks to the somatosensory feedback one receives when acting. For instance, if I knock my head on the shelf, it means that I am taller than the height of the shelf. Evidence also indicates that the body map can adjust to incorporate artificial extensions like tools. For instance, Sposito and colleagues (Sposito, Bolognini, Vallar, and Maravita, 2012) found that after tool use, participants mislocalized the center of their arms as if their arms were longer. But if tools can be incorporated in the body map just because one exerts control over them, then it seems that action must play a role for the body map. On this new version of the sensorimotor approach, one takes oneself to have two arms and two legs, of such respective size on the basis of past sensorimotor experiences. If so, one can expect the body map to represent body parts in terms of the possibilities of movement they afford, that is, in terms of bodily affordances (O'Shaughnessy, 1980; Bermúdez, 1998; Smith, 2009; Wong, 2009). The fact is that tactile localization is improved close to anatomical landmarks with functional salience like joints (Cholewiak and Collins, 2003). As joints have a special significance for action, there is only one step to conclude that the body map is endowed with a motor format.

Clearly, representations of bodily affordances are essential for planning action. They prevent one from attempting to move in biologically impossible or painful ways and from over- or under-reaching when trying to get an object. Still one may wonder whether these representations are fine-grained enough for bodily experiences. In a nutshell, if someone touches my forearm, the sensation is quite focal, localized in one specific area in a specific body part. By contrast, when I move my forearm, my hand and fingers follow. Parts of the body are brought together, unified by their functional role for action. How then can a rough-grained body map account for the focality of bodily experiences? In order to illustrate this worry, let us consider a study on the segmentation of the body into parts (de Vignemont, Majid, Jolla, and Haggard, 2009). We found that two tactile stimuli felt farther apart if they were applied on two distinct body parts across the wrist than within a single body part. This indicates that the body map that spatially organizes bodily experiences is structured into well-segmented body parts delineated by

the joint. We then asked participants to move their hand by rotating their wrist several times just before being touched. We found that the effect was reduced, although one might have expected the reverse. This result suggests that the relative overestimation of cross-joint distances cannot itself be a motor effect. On the contrary, action brings body parts together into functional units. The notion of functional unit actually appears as early as in the primary motor cortex, which is not as well segregated and segmented as that in primary somatosensory cortex (Hlustik, Solodkin, Gullapalli, Noll, and Small, 2001). To conclude, bodily experiences are framed by a representation of well-segmented body parts, representation that is of little use for action.

Interestingly, even for the body map used for action, it is not clear that it is built up exclusively on the basis of action. Sensorimotor feedback can give only a rough estimate of one's body metrics. For example, bumping my head does not indicate the respective size of my head, torso, and legs. Active exploration of each body part by haptic touch seems to fare better and to be more specific. However, this involves complex tactile-proprioceptive processing, and that in turn requires taking into account the size of the exploratory body parts (e.g. fingers). One should not believe that building up a representation of the body on the basis of action is a fast and costless solution. Rather, research in robotics indicates that it requires hundreds of interactions (Bongard, Zykov, and Lipson, 2006). Arguably, action helps to develop and calibrate a multimodal representation of one's own body. But it cannot be the only source of information. On the one hand, there must be an innate rough specification of the human body (such as two arms and two legs) (Melzack, Israel, Lacroix, and Schultz, 1997). If not, how could one explain phantom limbs in individuals with congenital limb deficiency? On the other hand, vision, which is the sense of space par excellence, is needed in order to fill in the specific details of the body map, such as body metrics. It is indeed the only sense that can directly and reliably process size information (Longo and Haggard, 2010). In particular, several studies show that the body map adjusts on the basis of visual information. For instance, one can induce an illusory distortion of the size of your hand, which affects both how you move your hand and how you feel touch (Taylor-Clarke, Jacobsen, and Haggard, 2004; Marino, Stucchi, Nava, Haggard, and Maravita, 2010). Even more surprisingly, the body map can incorporate an extraneous object that is only visually perceived, though one has no control over it, like in the rubber hand illusion (Botvinick and Cohen, 1998): if one looks at a rubber hand, while one's own hand is hidden, and both the rubber and the real hands are synchronously stroked, one reports feeling as if the rubber hand were part of one's body and one mislocates one's hand toward the rubber hand. Mere vision can thus alter the body map.

To conclude, I have explored two paths the sensorimotor approach to bodily awareness can take and showed that neither is satisfactory. First, one may claim that bodily experiences consist in sensorimotor laws. I argued that bodily know-how fails to account for the localization of bodily experiences in specific parts of one's body. Alternatively, one may claim that the body map that is required to account for the spatiality of bodily experiences is ultimately grounded in action and represents bodily affordances. I argued that the way one spatially represents the body differs in motoric and in non-motoric contexts. Should one then conclude that action plays no major role for bodily awareness? Not yet. There is indeed a further path a sensorimotor approach can undertake. So far I have focused on the experience of the space of the body. But as noted by O'Shaughnessy (1980), bodily experiences are "sensations-at-a-part-of-body-at-a-point-in-body-relative-space." Typically, when you feel your arm moving to the right, not only do you feel that it is your arm that is moving, but also that your arm is moving *over to the right*. Any account of bodily awareness must thus account both for the fact that one feels sensations in a specific part of the body and for the fact that one feels sensations in external space.

One may then suggest that action plays a role for the experience of the body in space, if not for the experience of the space of the body.

The body in space

Close your eyes and cross your hands. If you are touched briefly on the left hand and then rapidly after on the right, you will have difficulties in localizing in which hand the first touch was applied (Yamamoto and Kitazawa, 2001). This effect results from the conflict between two spatial frames of reference in which tactile experiences are encoded. If tactile experiences were located only relative to the body map, then bodily posture should make no difference. A touch on the right hand remains on the right hand no matter where it is located. The difficulties that you experience here, however, show that (i) the relative location of body parts matters and (ii) the location in the body map can be in conflict with the location in external space (for instance, a right hand on the left side of the body). The external frame of reference can be said to be egocentric: you locate the location of your hand in relation to you (on your left). Now a dominant view in philosophy is that the origin of the egocentric format of perceptual experiences can be found in action. For example, Evans (1985) defines egocentric space as the space of action, what he called a “behavioral space.” Since Evans, a number of philosophers have taken egocentric perceptual experiences as evidence for the implication of action in perceptual awareness (Brewer, 1997; Peacocke, 1992; Briscoe, 2008). It is true that egocentric frames are essential for action. In order to act toward an object, one needs to locate it relative to oneself. However, does this entail that sensorimotor processes are involved in bodily experiences?

The necessity of egocentric content for action does not show that the egocentric space in perceptual experiences is a space of action. Even if it primarily evolved for action, it may have detached itself from action and evolved differently when used in perceptual experiences. It is actually not even clear whether the same type of egocentricity is at stake in perception and in action. For instance, there is evidence that one can localize one’s body in two distinct egocentric frames. In the rubber hand illusion, we found that participants mislocalized their hand at a location close to the rubber hand. Yet, when asked to move it, their movement indicated that the motor system correctly localized it at its actual location (Kammers, de Vignemont, Verhagen, and Dijkerman, 2009). The egocentric location of one’s hand in bodily experiences can thus differ from the egocentric location used by the motor system. Furthermore, it was found that the effect of bodily posture due to the conflict between the bodily frame and the egocentric frame when the hands are crossed is erased when one is congenitally blind, but not when one becomes blind later in life (Röder, Rösler, and Spence, 2004). It thus seems that the key factor is not whether one can (or could) act or not. Obviously congenitally blind people can scratch their leg when it is itching. It is rather that one has had visual experiences during childhood. Only then can one acquire the egocentric frame upon which one can automatically remap one’s bodily experiences.²

Does it mean that action does not contribute to bodily awareness? Matthen (2005, p. 304) asks: “What would seeing – conscious vision – be like if we lacked motion-guiding vision?” He claims that it would lack a feeling of presence. Likewise, I will now argue that bodily experiences would be devoid of *feeling of bodily presence* if one lacked sensorimotor processing. When something brushes your face, not only do you feel a tactile sensation on your face, you also become suddenly aware of the presence of your face, which before remained at the background. Bodily sensations carry with them a sensation of physical presence or reality. The feeling of bodily presence has two distinctive features, what I shall call “externality” and “globality.”

First, when one is visually aware of an object as present in a scene, one experiences it in the external three-dimensional world. Likewise, one is aware of one's body as present in the external world. Another way to put it is that the body is not only an inner space. As Martin (1993, p. 211) says, it is experienced as being part of a "larger space, which can contain other objects." In visual experiences, externality is given by the fact that one can have different perspectives on the object. But one cannot feel one's body from different spatial perspectives. Rather, the feature of externality requires relating one's body to other objects or other bodies, upon which one can have different perspectives. In this sense, the feeling of bodily presence is relational. The second feature of the feeling of presence is its globality. In visual experiences, one is aware of the object as a whole, including its unseen sides. In the same way that objects have unseen sides, the body has unfelt regions. The feeling of bodily presence then consists in the awareness of the body part, including its unfelt regions. For example, although one feels sensations at a rather specific location on the body part (for example, in the middle of the left cheek), the feeling of bodily presence is more global, at the level of the whole body part (the head for instance), and possibly even beyond. It is not restricted to the limited area of the body in which one localizes the sensation.

Matthen (2005) argues that the origin of the feeling of presence can be found in the involvement of the dorsal stream of visuomotor processing for visual experiences of a visual scene. By contrast, he argues that visuomotor processing is not involved in visual experiences of a pictorial representation, which are thus devoid of feeling of presence. Roughly speaking, one feels the objects as present thanks to the fact that one knows one can act on them. Now the question is whether the same is true of bodily experiences.

I will now argue that the feeling of bodily presence is grounded in the sensorimotor processing of peripersonal space, that is, the space immediately surrounding one's body. When a threatening object enters a spatial margin of safety around the animal's body, animals engage in a range of protective behaviors. As Graziano and Gross (1993, p. 107) described it, the peripersonal space is like "a gelatinous medium surrounding the body that deforms whenever the head rotates or the limbs move." For example, in humans it was found that neutral visual stimuli close to a part of the body interfere with tactile experiences, if the location of the visual stimuli is incongruent with the location of the tactile stimuli (Spence, Pavani, and Driver, 2004). Interestingly, objects in peripersonal space are endowed with a special significance for the body. They may be perceived as potential threats or obstacles. One may then defend a sensorimotor interpretation according to which peripersonal space is defined in terms of the movements one can or should perform in relation to the objects perceived in peripersonal space. In Evans' terms, one can claim that peripersonal space is a "behavioral space." How is this notion of peripersonal space then related to the feeling of bodily presence?

George Orwell in his novel *1984* nicely illustrated how important the potential threat of an outside enemy is to strengthening the awareness of a country's borders (Orwell, 1949). Likewise, one may argue that one is aware of one's body as a single bounded object among others thanks to the processing of potential threat in peripersonal space. We have seen that the feeling of bodily presence is characterized by its "externality" and its "globality." I claim that peripersonal space can account for both features. On the one hand, the body part feels present in the external world in virtue of the fact that peripersonal space defines the relation between one's body and other objects. The fact that objects in peripersonal space are located relative to the same bodily frame of reference as bodily experiences creates a line between the inside and the outside, and thus leads to awareness of one's body as a bounded object. On the other hand, the body part feels present as a whole, including its unfelt regions, in virtue of the fact that the representation of peripersonal space is organized relative to the body map used for action.

Therefore, the part of the body that feels present in bodily experiences corresponds to the holistic functional segmentation of the body map for action. The feeling of bodily presence is thus traceable to sensorimotor processing of peripersonal space.³

One can then make two empirical predictions. On the one hand, patients who lack the feeling of bodily presence should have motor abnormalities. On the other hand, patients who have motor abnormalities are susceptible to loss of feeling of bodily presence. This has never been directly investigated, but some findings point in this direction in depersonalization disorder and in ideomotor apraxia. Patients with depersonalization disorder complain about abnormal bodily experiences, and in particular feelings of unreality. Typically they report “I have to touch myself to make sure that I have a body and a real existence” (Sierra and Berrios, 2000). In short, they lack the feeling of bodily presence. Interestingly, they also report abnormal action awareness, as if they had no control over their body. The psychiatrist Pierre Janet actually insisted that the disorder of depersonalization does not result from a sensory disorder, but rather from a motor disorder: “the feeling of emptiness is a trouble of action, not of sensation or misunderstood consciousness” (Janet, 1928, p. 101). Unfortunately, this has not been directly tested. I would predict for example that patients with depersonalization should have difficulties in motor imagery tasks and that they should have abnormal processing of peripersonal space.

Let us now consider the case of ideomotor apraxia, which clearly demonstrates motor disorder. Typically apraxic patients cannot imitate meaningless gestures or imagine movements in motor imagery tasks (Buxbaum, Giovannetti, and Libon, 2000). Interestingly, their introspective reports also reveal abnormal bodily experiences: “All the participants experienced to some degree that their hands had to be searched for, found, put in the right place and ‘monitored’ through the action” (Arntzen and Elstad, 2013, p. 69).

To conclude, I have argued in favor of a duplex conception of bodily experiences. Bodily experiences are localized in specific parts of the body thanks to a well-segmented body map. This body map, however, does not exhaust the spatiality of bodily experiences. When one feels sensations in a specific part of the body, one feels this body part as present thanks to the sensorimotor processing of peripersonal space. Consequently, the spatial content of bodily experience consists both in a relatively fine-grained perceptual spatial content and in the way our bodily experience presents parts of the body in relation to objects that surround it.

Conclusion

Bodily awareness is a multifaceted phenomenon, which can hardly be summarized in so short a contribution. Although bodily awareness and action seem to be intimately linked, it is actually hard to pinpoint the exact role of action for bodily awareness. I distinguished two main aspects of bodily awareness, the awareness of the space of one’s body and the awareness of the body in space. I argued against a sensorimotor approach of the bodily space. Action plays only a limited role in calibrating the mental representation of one’s body that spatially structures bodily experiences. On the other hand, I argued in favor of a sensorimotor approach of the body in space. More precisely, one is aware of the boundaries of one’s body in its relation to other objects thanks to sensorimotor peripersonal space.

Notes

- 1 Although there are some embodied theorists that reject the notion of mental representations, this does not need to be (Shapiro, 2011).
- 2 This is not to say that congenitally blind individuals have no egocentric reference frame in general. It only shows that they have different types of bodily experiences. Further evidence confirms this view,

including the fact that they do not experience the non-visual version of the rubber-hand illusion (Petkova, Zetterberg, and Ehrsson, 2012). For further detail, see de Vignemont (in press).

- 3 Now one may object that many animals have peripersonal space. Does one want to assume that they share this specific dimension of bodily awareness with humans? There is no reason why they should not. The feeling of bodily presence does not involve a first-personal component. It may be a condition for a sense of bodily ownership, but it is not a sufficient condition. At least, an animal can be aware of one's body as a bounded object without being aware of one's body qua one's own.

References

- Anema, H. A., van Zandvoort, M. J., de Haan, E. H., Kappelle, L. J., de Kort, P. L., Jansen, B. P., et al. (2009). A double dissociation between somatosensory processing for perception and action. *Neuropsychologia*, 47, 1615–20.
- Arntzen, C., and Elstad, I. (2013). The bodily experience of apraxia in everyday activities: A phenomenological study. *Disability and Rehabilitation*, 35(1), 63–72.
- Bermúdez, J. L. (1998). *The paradox of self-consciousness*. Cambridge, MA: MIT Press.
- Bongard, J., Zykov, V., and Lipson, H. (2006). Automated synthesis of body schema using multiple sensor modalities. In L. M. Rocha (Ed.), *Artificial Life: Vol. 10. Proceedings of the Tenth International Conference on the Simulation and Synthesis of Living Systems*. Cambridge, MA: MIT Press.
- Botvinick, M., and Cohen, J. (1998). Rubber hands “feel” touch that eyes see. *Nature*, 391(6669), 756.
- Brewer, B. (1997). Foundations of perceptual knowledge. *American Philosophical Quarterly*, 34(1), 41–55.
- Briscoe, R. (2008). Vision, action, and make-perceive. *Mind and Language*, 23(4), 457–97.
- Buxbaum, L. J., Giovannetti, T., and Libon, D. (2000). The role of the dynamic body schema in praxis: Evidence from primary progressive apraxia. *Brain and Cognition*, 44(2), 166–91.
- Cholewiak, R. W., and Collins, A. A. (2003). Vibrotactile localization on the arm: Effects of place, space, and age. *Perception and Psychophysics*, 65, 1058–77.
- de Vignemont, F., (2011). A mosquito bite against the enactive view to bodily experiences. *Journal of Philosophy*, 108(4), 188–204.
- (in press). A multimodal conception of bodily awareness. *Mind*.
- de Vignemont, F., Majid, A., Jolla, C., and Haggard, P. (2009). Segmenting the body into parts, evidence from biases in tactile perception. *Quarterly Journal of Experimental Psychology*, 3, 1–13.
- Evans, G. (1985). Molyneux's question. In *Collected papers*. Oxford: Oxford University Press.
- Gallagher, S. (2005). *How the body shapes the mind*. New York: Oxford University Press.
- Graziano, M. S., and Gross, C. G. (1993). A bimodal map of space: Somatosensory receptive fields in the macaque putamen with corresponding visual receptive fields. *Experimental Brain Research*, 97(1), 96–109.
- Hlustik, P., Solodkin, A., Gullapalli, R. P., Noll, D. C., and Small, S. L. (2001). Somatotopy in human primary motor and somatosensory hand representations revisited. *Cerebral Cortex*, 11(4), 312–21.
- Hurley, S. (1998). *Consciousness in action*. Cambridge, MA: Harvard University Press.
- Janet, P. (1928). *De l'angoisse à la extase*, Paris: Alcan.
- Kammers, M. P., de Vignemont, F., Verhagen, L., and Dijkerman, H. C. (2009). The rubber hand illusion in action. *Neuropsychologia*, 47, 204–11.
- Longo, M. R., and Haggard, P. (2010). An implicit body representation underlying human position sense. *Proceedings of the National Academy of Sciences of the United States of America*, 107(26), 11727–32.
- Marino, B. F. M., Stucchi, N., Nava, E., Haggard, P., and Maravita, A. (2010). Distorting the visual size of the hand affects hand pre-shaping during grasping. *Experimental Brain Research*, 202, 499–505.
- Martin, M. G. F. (1993). Sense modalities and spatial properties. In N. Eilan, R. McCarty and B. Brewer (Eds.), *Spatial representations*. Oxford: Oxford University Press.
- Matthen, M. P. (2005). *Seeing, doing, and knowing: A philosophical theory of sense perception*. Oxford: Oxford University Press.
- Melzack, R., Israel, R., Lacroix, R., and Schultz, G. (1997). Phantom limbs in people with congenital limb deficiency or amputation in early childhood. *Brain*, 120(9): 1603–20.
- Merleau-Ponty, M. (1945). *La Phénoménologie de la perception*. Paris: Gallimard.
- Morgan, R., and Rochat, P. (1997). Intermodal calibration of the body in early infancy. *Ecological Psychology*, 2(1), 1–25.
- Noë, A. (2004). *Action in perception*. Cambridge, MA: MIT Press.
- O'Regan, K. (2011). *Why red doesn't sound like a bell: Understanding the feeling of consciousness*. New York: Oxford University Press.

- O'Regan, K., and Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, 24(5), 939–101.
- O'Shaughnessy, B. (1980). *The will*. Cambridge: Cambridge University Press.
- Orwell, G. (1949). *Nineteen eighty-four*. London: Secker & Warburg.
- Paillard, J., Michel, F., and Stelmach, G. (1983). Localization without content: A tactile analogue of “blind sight.” *Archives of Neurology*, 9, 548–51.
- Peacocke, C. (1992). Scenarios, concepts, and perception. In T. Crane (Ed.), *The contents of experience*. Cambridge: Cambridge University Press.
- Petkova, V. I., Zetterberg, H., and Ehrsson, H. H. (2012). Rubber hands feel touch, but not in blind individuals. *PLoS One*, 7(4), e35912.
- Röder, B., Rösler, F., and Spence, C. (2004). Early vision impairs tactile perception in the blind. *Current Biology*, 14(2), 121–24.
- Schilder, P. (1935). *The image and appearance of the human body*. New York: International Universities Press.
- Shapiro, L. (2011). *Embodied cognition*. New York: Routledge.
- Sierra, M., and Berrios, G. E. (2000). The Cambridge Depersonalization Scale: A new instrument for the measurement of depersonalization. *Psychiatry Research*, 93(2), 153–64.
- Siewert, C. (2005). Attention and sensorimotor intentionality. In D. W. Smith and A. Thomasson (Eds.), *Phenomenology and philosophy of mind*. Oxford: Clarendon Press.
- Smith, A. J. T. (2009). Acting on (bodily) experience. *Psyche*, 15(1), 82–99. Retrieved from <http://www.theassc.org/files/assc/2581.pdf>
- Spence, C., Pavani, F., and Driver, J. (2004). Spatial constraints on visual-tactile cross-modal distractor congruency effects. *Cognitive, Affective, & Behavioral Neuroscience*, 4(2), 148–69.
- Sposito, A., Bolognini, N., Vallar, G., and Maravita, A. (2012). Extension of perceived arm length following tool-use: clues to plasticity of body metrics. *Neuropsychologia*, 50(9), 2187–94.
- Taylor-Clarke, M., Jacobsen, P., and Haggard, P. (2004). Keeping the world a constant size: Object constancy in human touch. *Nature Neuroscience*, 7(3), 219–20.
- Thompson, E. (2005). Sensorimotor subjectivity and the enactive approach to experience. *Phenomenology and the Cognitive Sciences*, 4(4), 407–27.
- Wong, H. Y. (2009). On the necessity of bodily awareness for bodily action. *Psyche*, 15(1), 31–48. Retrieved from <http://www.theassc.org/files/assc/2587.pdf>
- Yamamoto, S., and Kitazawa, S. (2001). Reversal of subjective temporal order due to arm crossing. *Nature Neuroscience*, 4(7), 759–65.

MEMORY AND ACTION

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Introduction

Traditional theories viewed memory as the “great storehouse of information.” Since the late 1960s, researchers have begun thinking of information as stored in the form of semantic networks. The general idea was that concepts were stored in nodes and that the links between nodes indicated an association between the concepts. Several decades later, it became clear that there is a fundamental problem with this view. The problem is that the concepts are merely labels in the network, for example the label “whale” or “tree.” The network is merely a connection of linked labels. The labels have no meaning to the network; they only have meaning to the user. As Harnad (1990) put it, the network is parasitic on us. He dubbed this the *grounding problem*. The grounding problem suggests that semantic networks as just described cannot be a model of human memory.

A great deal of research since the publication of Harnad’s influential paper has tried to solve the grounding problem. Mental representations need to be grounded in perception and action; they cannot be a free-floating system of symbols. A research tradition has emerged that tries to investigate how cognition is grounded in perception and action. Sometimes this research tradition is called “embodied cognition” but others, like the authors of this chapter, prefer the term “grounded cognition.”

The first publications in this emerging field addressed the question of how language processing is grounded in action and perception (Glenberg and Kaschak, 2002; Tucker and Ellis, 1998; Zwaan, Stanfield, and Yaxley, 2002). These studies suggested that there are interactions between language and perception and action. Over the years, convergent evidence on these mutual interactions of action and perception with cognitive processes have given rise to a promising line of research that explored ways in which different domains of cognition are grounded in various action and perception patterns (Barsalou, Simmons, Barbey, and Wilson, 2003; Borghi and Cimatti, 2010; Price, Peterson, and Harmon-Jones, 2012).

Theoretical discussions on the groundedness of cognition were initially of a general nature. They dealt with the intricate relations between body and brain (Damasio, 1994), perceptual symbol systems (Barsalou, 1999; Barsalou *et al.*, 2003), views on embodied cognition (Glenberg, 1997; Wilson, 2002) and simulation (Gallese, 2003). What they have in common is a disagreement with the traditional view of cognition that is burdened with the grounding problem

(Fodor, 1975, 1983). They also share a focus on the central role of the body in shaping the mind (Wilson, 2002).

This chapter will review embodied cognition perspectives and examples of empirical research within the context of a memory and action domain. Relevant insights on memory systems, the role of the body in cognitive processes, and neural substrates will be discussed here. This is followed by a more in-depth discussion of empirical research that relates to the memory and action theme with a focus on different motor domains, memory systems, and tasks involved. Expertise is addressed as a special form of action-cognition interaction and relates to memory-bias issues that are the result of motor fluency. The chapter continues with an exploration of new directions in memory and action research in the psychology of economics, law and collective remembering, and concludes with the evaluation of boundary issues and limitations of the embodied cognition approach that have been brought up recently (Mahon and Caramazza, 2008).

Theoretical perspectives on memory and action

Various perspectives on grounded cognition (Barsalou, 1999; Glenberg, 1997; Wilson, 2002), episodic memory (Rubin, 2006), and the neural architecture underlying recall and recognition (Damasio, 1989, 1994) converge on the idea that memory processes have specific neural underpinnings. Rubin considers episodic memory to be a collection of interacting basic systems, including vision, emotion, language, search and retrieval, explicit memory, narrative and motor systems in which each basic system has its own neural substrate (Rubin, 2006). For example, the search and retrieval system has its neural substrate in the frontal lobes, whereas explicit memory systems are based in the medial temporal lobe. The hippocampus and surrounding structures are relevant for binding aspects of a memory (Squire, Stark, and Clark, 2004). This notion of a neural basis of the basic systems is supported by research showing activation of different brain areas in the time course of retrieving an autobiographical memory (Daselaar *et al.*, 2005). At the start of the retrieval process, activation of areas associated with explicit memory and search and retrieval (hippocampus and prefrontal cortex) increases, whereas activity in the visual cortex reflects the re-experience or maintenance of an event once it is retrieved. This corresponds to increases in amygdala activation and higher subjective ratings of reliving the event during the retrieval process. The notion of interacting brain systems underlying memory retrieval and of memories being distributed across brain systems is a way of conceptualizing the grounding of cognition. In other words, the experience of an event and the reconstruction of an event when it is being retrieved occurs in a similar way and with the same brain activation and same systems involved as during the original experience. This is consistent with Damasio's theory of the neural architecture underlying recall and recognition (1989), in which activity occurs in multiple brain areas near the sensory portals and motor output regions. Thus, instead of a single place for the integration of sensory and motor processes, multiple ones exist that are also recursive and iterative. The integration occurs in "convergence zones," zones that bind features of a sensory or motor activity into single entities and then bind entities into events or sets of events. This process of binding causes the integration of features and events at both perceptual and cognitive levels.

Components of Damasio's theory of a neural architecture underlying recall and recognition are also reflected in Barsalou's theory of grounded cognition (1999; Barsalou *et al.*, 2003). Cognition is grounded through the process of simulation. When retrieving an experience, neural states are re-enacted from action, perception and introspective systems. Perception covers

the sensory modalities, the motor modality includes movement and proprioception, and introspection is a modality that is comprised of affective states, mental models, and motivation. Together, these modalities are responsible for different aspects of experience. For example, when a stimulus (a horse) is being perceived visually, neural feature detectors are active in the visual system. Conjunctive neurons that are located in an association area nearby in the brain combine these active features to store them in memory for later retrieval. When there is no more visual input, these neurons can reactivate the original set of features to a certain extent in order to make a similar visual representation of the horse that was seen before. This is considered a simulation. Simulations are rich in detail because of their multimodal nature; they do not contain only the visual (or other sensory) state when the stimulus was first perceived or the event was first experienced but also encompass the relevant motor and mental states that were part of the original experience. The result is an experience of reliving the situation during the re-enactment phase. A second idea that embodied cognition perspectives have in common is adherence to a central role of the body in cognitive processes. Applied to the memory domain, cognitive processes are a way to support appropriate action for a certain situation not by remembering what the situation is but by remembering the relevance of the action for that situation (Wilson, 2002). For example, visual memory can prime appropriate subsequent motor activity in tasks where perceiving the size and dimensions of a certain shape, such as a rectangle, aids performance on a subsequent task that requires a motor action, such as grasping an object that is the same shape or orientation as the shape observed before (Craighero, Fadiga, Umiltà, and Rizzolatti, 1996). Other types of memory are similarly embodied. Verbal rehearsal and counting on one's fingers are action patterns to facilitate short-term memory. Episodic memory retrieval, such as describing yesterday's party, is related to the body because relevant sensorimotor aspects of the event are reconstructed along with details of what the party was about (Bietti, 2012). Implicit memory is also based on action patterns of the body because motor skills that are difficult to learn initially (such as riding a bike) become automatized with practice and can bypass the representational bottleneck that is encountered when learning new things under time pressure.

Glenberg's view on grounded cognition (1997) also focuses on the relationships between memory and action. Specifically, memory can be defined in terms of integrated sets of action patterns that are constrained by our bodies. When a new instance of an action is undertaken, for example cooking a meal on a stove, previous cooking experiences with certain foods that have been left on the stove for too long come into play. New action patterns (setting a timer while cooking) may be an adjustment of earlier ones and be incorporated into memory for these actions. Conscious recollection is therefore a form of action pattern completion that is reconstructive by nature. These action patterns are constrained by how an individual can move his body and manipulate objects in a particular environment. For example, reaching for a cup on the other side of the table requires a different kind of movement and grip than reaching for a pencil that is right in front of you. In general, grounded and embodied cognition views action preparedness to be a basic function of cognition. Memory is especially important in offline tasks where actions do not take place in the "here and now" but involve remembering action patterns and information from the past, anticipating or planning things in the future, or imagining events that may never take place. The mutual relatedness between the body and the mind, or, more specifically, between memory and action and perception, implies that manipulations of the body and movement may result in memory changes, and vice versa. Motor fluency and expertise in complex motor movements may facilitate and enhance memory performance but might also lead to memory errors when motor fluency overrules decision-making processes. In the next section, empirical support for these assumptions is reviewed.

Empirical support for memory and action

Effects of the body and action patterns on memory processes have been demonstrated in a variety of studies in different domains and for various tasks (e.g. Dijkstra, Kaschak, and Zwaan, 2007; Casasanto and Dijkstra, 2010; Seno, Kawabe, Ito, and Sunaga, 2013; Yang, Gallo, and Beilock, 2009). These studies show that manipulations to the body result in changes in memory performance, or vice versa, that manipulations in the task result in bodily changes, suggesting mutual relationships between the body and memory processes.

The effect of body position on the ease of retrieval was examined in an autobiographical memory study (Dijkstra *et al.*, 2007). Participants assumed a body position either congruent or incongruent with the original body position during a memory-retrieval event (“Tell me about a time you were at the dentist office?” – congruent: lying down on a recliner; incongruent: standing with feet wide and hands on the hips). Response times for the retrieval of the memories were calculated from the video-recording of the experimental session. Two weeks later, participants were asked which memories they remembered from the experimental session in a free recall task. The results indicated faster responses for memories that were retrieved during the experimental session in congruent compared with incongruent body positions. Moreover, participants demonstrated better free recall later of congruent than incongruent memories. Adopting a congruent body position apparently helped to reconstruct the earlier experience, which resulted in better memory access and a stronger memory trace over a long period of time. The findings suggest that memory retrieval involves an embodied simulation of the original experience that includes body position. Having relevant sensorimotor aspects from the original experience available for memory retrieval facilitates the ease and durability with which this happens. Can body movements in contrast to position have an impact on autobiographical memory retrieval as well? A study by Casasanto and Dijkstra (2010) assessed the effect of motor actions on access to and content of autobiographical memories by examining how positive and negative emotions were expressed in the context of spatial metaphors of verticality, such as cheering when our favorite soccer team wins or sitting slumped with our head in our hands when it loses. During the experiment, participants deposited marbles upward or downward from one box into another, creating a movement that was by itself unrelated to the task of retrieving memories to positive or negative prompts (“Tell me about a time you were proud/ashamed of yourself”) but tapped into the association of the spatial metaphor and matching emotion: up = positive, and down = negative. In the first experiment, participants were faster recounting memories during schema-congruent (up = positive, down = negative) than schema-incongruent movements. In the second experiment, participants retrieved memories to valence-neutral prompts while making the same upward or downward movements with the marbles. After recounting the memories, they evaluated the memories as either positive or negative, based on their emotional content. The results indicated that participants evaluated the memories more positively after they were initially retrieved during upward movements and more negatively after they were initially retrieved during downward movements with the marbles. Motor actions did not only seem to facilitate access to one’s memories when these actions are congruent with the valence of the memories but they also affected the emotional content of the memory if a neutral retrieval cue was provided. These findings underscore the effect of body movement in a memory task, influencing both access and content via schematic representations of up-down and positive-negative associations. A similar association between body position and emotion content was examined in a study that looked at the activation of emotion concepts on changes in posture (Oosterwijk, Rottevel, Fischer, and Hess, 2009). Participants generated words that were associated with positive and negative emotions, such as “pride” and “disappointment,”

based on the idea that this generation task should tap into the conceptual system in which associations of certain emotion concepts with action patterns are stored (pride = positive = upward position, disappointment = negative = downward position). At the same time, their posture height was measured with a hidden camera. This way, changes in posture due to the generation of pride or disappointment words could be measured. The results indicated that when participants generated disappointment words, their posture became more slumped, making their height lower than it was when they generated pride words. The results support the embodied cognition perspective that conceptual knowledge arises from action patterns and bodily states.

The link between the body and autobiographical memory retrieval has been examined in a motorically more indirect manner as well by manipulating the illusion of self-motion perception, or “vection” (Seno *et al.*, 2013). Vection occurs when someone is observing upward- or downward-moving stimuli and having the illusion of self-motion in an opposite direction to the motion of the observed stimuli. Such a manipulation provides a way to disentangle possible visual effects of motion direction (watching up-down movements) from self-motion direction effects (making up-down movements) and to address the question whether this illusion can affect the emotional valence of autobiographical memories. If visual direction motion is important, upward vection would yield the generation of memories classified as positive. However, if self-motion direction is important, upward motion vection would result in the generation of memories classified as negative because the illusion is created that one moves downward. The results supported the prediction that both actual self-motion (Casasanto and Dijkstra, 2010) and illusory self-motion (Seno *et al.*, 2013) can modulate the emotional valence of recollected memories.

These studies illustrate how body position and (illusory) body movement facilitate access to autobiographical memories and may affect the emotional content of the memory. The effects are the result of the reconstruction of relevant aspects of the initial experience by virtue of body and action patterns that facilitate the reconstruction process and by the activation of concrete experiences associated with abstract concepts for which a mapping of action patterns (up-down) with concepts (emotions) exists. According to Barsalou, this reconstruction process can be biased due to selective attention and re-enactment of only a subset of represented features (1999). For example, overlearned action patterns may hinder the ability to differentiate between patterns that were or were not observed previously. A bias in reconstruction and motor fluency may therefore have the potential to create memory errors.

Yang and colleagues examined such an effect of an overlearned ability of motor movement, “motor fluency,” on later recognition (Yang *et al.*, 2009). Based on the phenomenon that an item’s visual clarity can alter its perceptual fluency, the idea was that the same could happen with regard to motor fluency. If observing the letter “p” leads to a covert simulation of the action of typing the letter “p” (with the little finger on your right hand if you are a typist), then this motor simulation should cause a feeling of familiarity. The activation of action plans associated with the stimuli could then impact memory judgments, resulting in decision errors on a recognition task. In the experiment, skilled typists and novices studied a list of letter dyads that would normally be typed with the same finger (reflecting lower motor fluency because the same finger cannot be at more than one place at a time) or with different fingers (reflecting higher motor fluency). Skilled typists were expected to falsely recognize the letter that would be easier to type (have higher motor fluency). The results supported this assumption. Expert typists, who have more consistent mappings between specific letters and motor plans to type them, made more false recognition errors to different-finger letter dyads than non-fluent dyads. In contrast, typing novices did not show motor-fluency effects in recognition memory.

Recognition memory seems to be affected by the covert simulation of actions associated with the dyads being evaluated. Motor fluency as a result of expertise development can lead to a reconstruction bias and makes experts more vulnerable to false recognition. Expertise in complex motor movements can also have beneficial effects on memory, however, which has been demonstrated in other studies conducted within the embodied cognition domain.

Boschker and colleagues demonstrated benefits of expertise built up from motor fluency of complex movements in combination with affordances in the environment (Boschker, Bakker, and Michaels, 2002). They wondered whether expert climbers would perceive climbing affordances to a greater extent than structural features of a climbing wall and remember climbing routes of wall elements better than less-experienced climbers. A climbing wall offers affordances for climbing if a hold affords grasping and is not too far away from another hold in order to afford reaching by hand or foot. Experts were expected to remember climbing routes as possible action movements based on their earlier climbing experiences and recollect this route in a way that reflects these affordances. This was exactly what was found. Expert climbers also directed their attention to the important aspects of the climbing wall more than less-experienced climbers. Differences in skill level thus coincided with corresponding differences in visual perception and memory. Experts' superior climbing experience would therefore, not only help them climb faster and more efficiently, but also enhance their memory performance on climbing-related tasks.

Benefits of expertise for complex movements was also demonstrated in expert dancers. Calvo-Merino and colleagues (Calvo-Merino, Glaser, Grèzes, Passingham, and Haggard, 2005) speculated that the human mirror system might be sensitive to the degree of correspondence between the observed action and motor capability of the observer. They accordingly assessed whether expertise in performing dance movements that belonged to their action repertoire would yield a difference in brain activity compared with dance movements that did not belong to their action repertoire. During the experiment, expert ballet and capoeira dancers watched the same videos of ballet and capoeira movements while in an fMRI scanner. They had motor experience with one set of movements but not the other. The results indicated stronger BOLD (blood-oxygenation-level-dependent) responses in mirror areas of the brain when they observed dance movements from their own motor repertoire than when observing kinematically comparable dance movements they could not perform themselves. Thus, as expected, participants responded according to their own motor expertise. The mirror system in the brain, typically active when observing others, does not seem to respond simply to visual kinematics of body movement but transforms visual inputs into the specific motor capabilities of the observer. This supports simulation theories in which action perception involves covert motor activity.

The studies discussed above support the “memory is for action/action is for memory” assumption deriving from the embodied cognition perspective. Action patterns in these studies were relevant for a certain situation, activated existing mappings between abstract concepts and concrete experiences, and evolved to complex, automatic patterns with specific neural underpinnings among experts. Access to and retention of memories can be facilitated, and memory content can be affected, when appropriate action patterns are executed that facilitate the reconstruction process of a previously experienced event. Under certain circumstances, cognitive bias may occur when motor fluency overrules the decision process, but action expertise with complex movements also produces brain activation of related areas and recall of relevant information in the environment. Overall, these research findings are consistent with the thesis that memory is embodied in the sense that it interacts with action systems and shares a common neural basis with action.

Other approaches

Our focus in this discussion so far has been on the relationship between memory and the motor system. Presenting all of the existing research in this domain exceeds the purpose of this chapter. Many other studies have supported the neural basis of cognitive processes and relationships between memory and action in other memory domains (Crawford, 2009; McNorgan, 2012). Our focus has been on the motor system but many other studies have been conducted focusing on other modalities. A study on the role of body scaling in memory when action is not immediate (Twedt, Crawford, and Proffitt, 2012) showed that participants were most accurate in judging target height from memory when it was closest to their own height. Davoli and colleagues conducted a study on the role of the body within the visual memory domain (Davoli, Brockmole, and Witt, 2012). They tested the adaptivity of changes in cognitive processing of direct and remote interactions. Participants judged and remembered the distance of a target 30 meters away to be closer when they illuminated the target with a laser pointer than when they pointed at it with a baton. Previous interactions with these tools resulted in a distorted perception of how far away the object was (Davoli *et al.*, 2012). A new trend in embodied cognition research is to examine the groundedness of cognition in action and perception from an interdisciplinary perspective. Embodied perspectives have informed investigations in clinical psychology and in the psychology of law, discourse processes and collective remembering. In each case, researchers pursue novel combinations of current themes involving contributions of action and perception patterns in cognitive processing. Several applications of embodied cognition in different disciplines were proposed by Davis and colleagues (2012). One possible application of embodiment in the legal system involves study of the interactions between the body and cognitive processes in legal contexts as they may affect the outcome of judges' and jurors' decision making. Such studies examined the relationship between hand-washing (a form of physical purity) and moral purity (Schnall, Benton, and Harvey, 2008), and the potential bias of eyewitnesses as a result of (suggestive) gestures (Broaders and Goldin-Meadow, 2010). Other possible applications of embodiment in relatively unexplored fields extend an embodied approach to reading, art perception and music cognition (Davis *et al.*, 2012; Naveda and Leman, 2010).

A more theoretical interdisciplinary approach to embodied cognition has been articulated by Bietti (2012) who makes a case for the interdependencies of cognition and embodied discourse practices in the process of collective remembering. Cognitive, embodied, discursive and pragmatic processes all contribute to the reconstruction and communication of memories in social environments through intricate interactions that develop from the construction of situation models when processing information. Situation models integrate information from different modalities and provide memory traces in episodic memory that may be updated when new situation models are created. Conversations allow for a reconstruction of individual and shared memories and a natural means to communicate them. Eye gaze and body posture may support a conversational alignment of the communication partners by expressing interest (leaning toward the other) or disinterest (leaning away from the other) in what the communication partner conveys. New interdisciplinary approaches in embodied cognition can be entirely different as well. A clinical application was conducted by Marangolo and colleagues (Marangolo, Cipollari, Fiori, Razzano, and Caltagirone, 2012), who included patients with aphasia in a study on the role of action observation treatment on verb recovery. These patients had a selective deficit in verb retrieval and participated in a training program that included observation of action video clips after which they had to indicate the appropriate verb with the clip. The training worked for the video clips of human actions (eating) but not for non-human actions (barking). Because

the human action verbs are grounded with sensorimotor features, and are part of the motor repertoire of the person observing them, performing and observing the action interacts with the semantic system and therefore enhances the activation of the corresponding representation and the retrieval of the relevant verb.

These approaches explore new ways and domains of investigating embodiment by looking beyond potential barriers of the embodied cognition view. The interdependencies between action, perception and cognition are well known by now within the field of cognitive psychology. This is not yet true in clinical or legal psychology or in the arts, despite the possibility that embodied approaches could fuel a promising line of research to reveal other ways in which the body affects cognition and perception. A different development within the current theoretical debate regarding embodied cognition goes in the opposite direction, revealing a need to define the boundaries and limitations of the embodied cognition approach and to develop alternative explanations for the available evidence.

One alternative view postulates that actual cognitive processing is performed by abstract amodal symbolic systems and that activation cascades down into sensorimotor systems (Mahon and Caramazza, 2008). Thus, this *interactive view* takes an intermediary position between the traditional “disembodied” view and the grounded view. It will be a major challenge to distinguish empirically between the interactive and the grounded view because the two views make very similar predictions. Another major challenge is to develop a convincing account of how abstract information is processed. Barsalou and Wiemer-Hastings (2005) provide an interesting start. In their view, abstract concepts are not fundamentally different from concrete ones. They are both mental representations of situations. In the case of concrete concepts, the representation has a focal entity (the object), whereas the focus is more diffuse in the case of abstract concepts. However, the focus becomes clear once the concept is situated. For example, a concrete concept like BRIDGE has a focal entity that is in a situation (e.g. it is situated across an expanse of water), whereas an abstract concept like DEMOCRACY does not have a focal entity, although one can be constructed in a specific instantiation of the concept (e.g. a voting booth). As yet, there is not a great deal of evidence that speaks to this view.

In conclusion, although the grounded view of memory has received a considerable amount of empirical support, the extant empirical evidence is limited in that it pertains mostly to concrete concepts. In addition, alternative accounts have emerged that are a hybrid between the traditional view and the grounded view. The viability of the grounded view will depend on efforts to differentiate it empirically from other views (and vice versa) and on its ability to deal with abstract concepts, both theoretically and empirically. An interdisciplinary perspective may be the best hope to overcome current barriers to the embodied cognition view and to articulate where the interplay between memory and action ends.

References

- Barsalou, L. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, 22, 577–660.
- Barsalou, L. W., Simmons, W. K., Barbey, A. K., and Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences*, 7, 84–91.
- Barsalou, L. W., and Wiemer-Hastings, K. (2005). Situating abstract concepts. In D. Pecher and R. Zwaan (Eds.), *Grounding cognition: The role of perception and action in memory, language, and thought* (pp. 129–63). New York: Cambridge University Press.
- Bietti, L. M. (2012). Towards a cognitive pragmatics of collective remembering. *Pragmatics & Cognition*, 20, 32–61.
- Borghini, A. M., and Cimatti, F. (2010). Embodied cognition and beyond: Acting and sensing the body. *Neuropsychologia*, 48, 763–73.

- Boschker, M. S. J., Bakker, F. C., and Michaels, C. F. (2002). Memory for the functional characteristics of climbing walls: Perceiving affordances. *Journal of Motor Behavior*, 34, 25–36.
- Broaders, S., and Goldin-Meadow, S. (2010). Truth is at hand: How gesture adds information during investigative interviews. *Psychological Science*, 21, 623–28.
- Calvo-Merino, B., Glaser, D. E., Grèzes, J., Passingham, R. E., and Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral Cortex*, 15, 1243–49.
- Casasanto, D., and Dijkstra, K. (2010). Motor action and emotional memory. *Cognition*, 115, 179–85.
- Craighero, L., Fadiga, L., Umiltà, C. A., and Rizzolatti, G. (1996). Evidence for priming effect. *NeuroReport*, 8, 347–49.
- Crawford, E. (2009). Conceptual metaphors of affect. *Emotion Review*, 1, 129–39.
- Damasio, A. R. (1989). Time-locked multiregional reactivation: A systems-level proposal for the neural substrates of recall and recognition. *Cognition*, 25–62.
- Damasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain*. New York: Avon Books.
- Daselaar, S. M., Rice, H. J., Greenberg, D. L., LaBar, K. S., Rubin, D. C., and Cabeza, R. (2005). Time course of episodic retrieval activity: Brain regions involved in constructing and maintaining autobiographical memories. Paper presented at Annual meeting of the Society of Neuroscience, Washington, DC.
- Davis, J. I., Benforado, A., Esrock, E., Turner, A., Dalton, R. C., van Noorden, L., and Leman, M. (2012). Four applications of embodied cognition. *Topics in Cognitive Science*, 4, 786–93.
- Davoli, C. D., Brockmole, J. R., and Witt, J. K. (2012). Compressing distance with remote tool use: Real, imagined, and remembered. *Journal of Experimental Psychology: Human Perception and Performance*, 38, 80–89.
- Dijkstra, K., Kaschak, M. P., and Zwaan, R. A. (2007). Body posture facilitates retrieval of autobiographical memories. *Cognition*, 102, 139–49.
- Fodor, J. A. (1975). *The language of thought*. Boston, MA: Harvard University Press.
- (1983). *The modularity of mind: An essay on faculty psychology*. Cambridge, MA: MIT Press.
- Gallese, V. (2003). The manifold nature of interpersonal relations: The quest for a common mechanism. *Philosophical Transactions of the Royal Society of B: Biological Sciences*, 358, 517–28.
- Glenberg, A. M. (1997). What memory is for. *Behavior and Brain Sciences*, 20, 1–55.
- Glenberg, A. M., and Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review*, 9, 558–65.
- Harnad, S. (1990). The symbol grounding problem. *Physica D*, 42, 335–46.
- Mahon, B. Z., and Caramazza, A. (2008). A critical look at the embodied cognition hypothesis and a new proposal for grounding conceptual content. *Journal of Physiology – Paris*, 102, 59–70.
- Marangolo, P., Cipollari, S., Fiori, V., Razzano, C., and Caltagirone, C. (2012). Walking but not barking improves verb recovery: Implications for action observation treatment in aphasia rehabilitation. *PLoS One*, 7, 1–6.
- McNorgan, C. (2012). A meta-analytic review of multisensory imagery identifies the neural correlates of modality-specific and modality-general imagery. *Frontiers in Human Neuroscience*, 6(285).
- Naveda, L., and Leman, M. (2010). The spatiotemporal representation of dance and music gestures using topological gesture analysis (TGA). *Music Perception*, 28, 93–111.
- Oosterwijk, S., Rotteveel, M., Fischer, A. H., and Hess, U. (2009). Embodied emotion concepts: How generating words about pride and disappointment influences posture. *European Journal of Social Psychology*, 39, 457–66.
- Price, T. F., Peterson, C. K., and Harmon-Jones, E. (2012). The emotive neuroscience of embodiment, *Motivation and Emotion*, 36, 27–37.
- Rubin, D. C. (2006). The basic-systems model of episodic memory. *Perspectives on Psychological Science*, 1, 277–311.
- Schnall, S., Benton, J., and Harvey, S. (2008). With a clean conscience: Cleanliness reduces the severity of moral judgments. *Psychological Science*, 19, 1219–22.
- Seno, T., Kawabe, T., Ito, H., and Sunaga, S. (2013). Vection modulates emotional valence of autobiographical episodic memories. *Cognition*, 126, 115–120.
- Squire, L. R., Stark, C. E., and Clark, R. E. (2004). The medial temporal lobe. *Annual Review of Neuroscience*, 27, 279–306.
- Twedt, E., Crawford, L. E., and Proffitt, D. R. (2012). Memory for target height is scaled to observer height. *Memory & Cognition*, 40, 339–51.
- Tucker, M., and Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 830–46.
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, 9, 625–36.

- Yang, S., Gallo, D. A., and Beilock, S. L. (2009). Embodied memory judgments: A case of motor fluency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 35, 1359–65.
- Zwaan, R. A., Stanfield, R. A., and Yaxley, R. H. (2002) Language comprehenders mentally represent the shapes of objects. *Psychological Science*, 13, 168–71.
- Zwaan, R. A., and Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General*, 135, 1–11.

THE EMBODIMENT OF ATTENTION IN THE PERCEPTION-ACTION LOOP

Michael J. Spivey and Stephanie Huettenlocher

Introduction

Decades ago, the sciences of mind were busy drawing insights from computer engineering. Cognitive scientists reasoned that if a computer can process information in an intelligent fashion, perhaps humans are exhibiting their intelligence via similar mechanisms. It was thought that we could “reverse engineer” the human mind by drawing an analogy to how a computer is engineered. Of course, this was not the first time that a new and exciting piece of technology had been used as a metaphor for the mind. The Greeks likened the mind to a water pump, eighteenth-century Western philosophers likened the mind to a clock, and then theories of cognition were inspired by the steam engine, then by the telegraph, then by relay circuits, and now the computer (see Daugman, 1993). After using the computer metaphor for several decades now, is it possible that the insights it can provide have all been plumbed?

This chapter describes a series of examples of where the computer metaphor of the mind breaks down, with a special emphasis on attention, and points to an embodied and situated account of mind that can naturally accommodate those problematic phenomena that undermine the computer metaphor. Rather than proposing the next new metaphor for the mind, we instead encourage drawing eclectic inspiration from embodied cognition (to appreciate how the body itself performs some cognitive operations), ecological psychology (to appreciate how the relation between organism and environment produces cognition), dynamical systems theory (to carry out analog information-processing simulations), and cognitive neuroscience (to stay grounded with the real physical material that lies at the hub of cognitive phenomena).

Stage-based models of attention

Early models of attention were based on the assumption that the vast onslaught of raw uninterpreted sensory input that barrages our sensors must be filtered down to a small subset of processed cognitive items that would be analyzed by a central executive with limited capacity. This perspective inspired “filter” models of attention, that immediately drew a distinction between “pre-attentive” filters that processed a full sensory array of information in parallel, and “attentive” filters that processed a condensed set of information serially, one item at a time

(Broadbent, 1958; Treisman, 1969; see also Lachter, Forster, and Ruthruff, 2004). An example of a pre-attentive filter could be a topographically arranged collection of color-sensitive neurons in visual cortex, functioning like a feature-map that detects, say, the color red anywhere in the visual field. Due to its parallel processing, this feature map will locate a solitary red target in the visual field essentially immediately, no matter how many non-red distractor objects are there. Therefore, reaction times do not increase as one adds non-red distractor objects. By contrast, if the target can only be identified by a conjunction of two features, say red and vertical (because there are some red non-vertical distractors and also some non-red vertical distractors), then the “redness” feature map and the “verticalness” feature map will each have multiple regions of activation on them – making pre-attentive identification of the lone target impossible. In this circumstance, the feature integration theory (Treisman and Gelade, 1980) of visual search proposed that attention must combine those feature maps into a “master map,” and this master map is searched serially, as though by a spotlight that focuses on each object one at a time until the target is found. The feature integration theory of visual search was a powerfully influential filter-based account of attention for more than a decade.

However, a number of findings posed problems for the model. For example, some conjunctions of certain types of features appear to elicit parallel search processing, rather than serial (Nakayama and Silverman, 1986). Continuous gradations in similarity between a target and its distractors account for reaction time patterns better than treating visual features as discretely belonging to one feature map or another (Duncan and Humphreys, 1989). Analysis of a million trials across dozens of visual search experiments reveals no evidence for one population of serial search phenomena and a separate population of parallel search phenomena (Wolfe, 1998). And when the visual display spends its first 100 milliseconds configured with a single feature distinguishing the target, before then converting to a conjunction of features, one sees neither a parallel search nor a serial search, but something clearly in-between (Olds, Cowan, and Jolicoeur, 2000). These types of findings all led to treating visual search as belonging on a continuum of efficiency, rather than being implemented by either a pre-attentive parallel filtering mechanism or an attentive serial filtering mechanism. As the passive feedforward filter approach to visual attention failed to account for new findings, it made room for a more proactive goal-oriented approach to attention (Allport, 1989). Rather than the emphasis being on how perceptual systems convert stimuli into interpretations, a new emphasis was building on how attention results from motor systems making real-time demands on what sensory input is needed or expected next (Hommel, Müsseler, Aschersleben, and Prinz, 2001; Jordan, 1999; Kawato, 1999; van der Heijden, 1996; see also Gibson, 1979).

Interactive models of attention

This more proactive approach to attention raises the question: Where in this goal-oriented account of attention do the goals come from? Desimone and Duncan (1995) proposed a neurally inspired account of visual attention in which neural representations of objects (i.e. Hebbian cell assemblies, or population codes) compete against one another in parallel for the privilege of eliciting their associated motor output, such as an eye movement or a reaching movement. Neural feedback projections from frontal brain regions to visual brain regions can then bias this competition process based on goals and other information from other sensory sources. This “biased competition” account of attention has been extremely influential, and naturally makes a number of empirical predictions that have indeed been reported in the experimental literature.

For example, when a visual stimulus is especially relevant for the goals of a visuomotor task, single-cell recording in monkeys shows that neurons responsive to that stimulus exhibit a higher

firing rate than when that same visual stimulus is presented to that receptive field but is irrelevant to the task (Moran and Desimone, 1985; Motter, 1993). Moreover, fMRI results with humans show that when a tactile precue is spatially congruent with a visual stimulus, activation in visual cortex for that visual stimulus is greater than when the tactile precue is spatially incongruent (Macaluso, Frith, and Driver, 2000). Visual input of a face can trick the process of speech recognition into perceiving a spoken syllable one way or another (McGurk and MacDonald, 1976). Auditory input can trick the visual system into perceiving a visual event one way or another (Sekuler, Sekuler, and Lau, 1997; Shams, Kamitani, and Shimojo, 2000). And spoken linguistic input can make a conjunction search process function as though it were a parallel process, uninfluenced by the number of distractors (Chiu and Spivey, 2011; Spivey, Tyler, Eberhard, and Tanenhaus, 2001). In sharp contrast to Fodor's (1983) proposal of sensory systems as informationally encapsulated modules, these kinds of findings support a radically interactive and distributed account of attention, where even purportedly "unimodal" perceptual systems are being biased by other modalities (Driver and Spence, 2000; Lupyan and Spivey, 2008; O'Reilly, Wyatte, Herd, Mingus, and Jilk, 2013).

Cascaded models of attention

Even if every subsystem is influencing practically every other subsystem, this leaves open the question of how immediately those influences are transmitted. Traditional stage-based accounts of processing function by having each stage complete its operations before then passing an output to the next stage. This is quite different from a type of system that functions on partial, fuzzy, incomplete, and distributed information that is constantly in flux. It may feel counter-intuitive to think of attention as something this diffuse and partial – rather than it being narrow and directed – but many studies have shown that we operate as best we can with a constant flow of partial bits and pieces of information (Coles, Gratton, Bashore, Eriksen, and Donchin, 1985; for review, see Spivey, 2007).

The cascade model put forth by McClelland (1979) posits a few components to this kind of account, namely that the inputs to a particular level of processing are based on the outputs from the neighboring level(s), and that at each level of processing, the output is continuously available to the neighboring level(s). That is to say, the output is not a singular symbol or conclusion, but rather an unfolding of activation that is continuously being streamed to the neighboring level(s). Thus, the activation at any given level is determined by the connections between levels, as well as the pattern of activation in the neighboring level(s).

A cascaded flow of information from perceptual systems to motor systems is particularly well demonstrated by the work of Gold and Shadlen (2000). While briefly presenting a somewhat ambiguous visual stimulus to a monkey, to which it was trained to respond with an eye movement to one or another response location, they microstimulated cells in its frontal eye fields (FEF) to elicit a neutral direction of eye movement. With more and more time to process the visual stimulus, this electrically evoked saccadic eye movement showed more and more partial influence of the monkey's voluntary response eye movement, averaged into the angle of the neutral evoked saccade. Thus, over the course of a few hundred milliseconds, the continuous accrual of perceptual information in visual brain areas was constantly cascading into oculomotor brain areas to contribute to the gradual development of an eye movement command. When microstimulation then triggered the evoked saccade in a neutral direction, some portion of that still-developing voluntary response was also active in FEF. The resulting movement was a weighted average of the evoked neutral saccade and the partially accrued command for the voluntary response saccade. Clearly, the motor system is not patiently waiting

to be delivered a completed command from the cognitive system, but is instead continuously participating in the development of the understanding of what a stimulus means for the organism – thus blurring the line between what is “motor” and what is “cognitive.”

This kind of partial processing can be found in many decision-making tasks, where information can cascade through the system even without subjective awareness. Van Rullen and Thorpe (2001) trained participants to rapidly identify whether an animal or means of transportation was present in a picture, displayed for a mere 20 milliseconds on the screen and then masked. Animal and transportation trials occurred in separate blocks, and responses were made via a go, no-go paradigm. Participants were extremely accurate in this task (94 percent correct on average) in identifying whether these objects were present or not. An initial interpretation of this result might be that in a mere 20 milliseconds of input, the feedforward sweep of sensory information appears to be enough to carry out visual object identification in a seemingly context-free manner (before frontal brain regions would have time to respond and send feedback to visual areas). However, this neglects the fact that the task of identifying a pre-specified object’s presence or absence is itself a goal-oriented task. Goals are driven by frontal and prefrontal cortex, which has feedback connections to visual cortex. What is likely happening in this scenario then is not a context-free feedforward sweep whereby some particular category is rapidly identified, but rather the goal of looking for this target, even before a stimulus is presented, involves feedback signals from frontal regions tuning those visual receptive fields to temporarily become “car detectors” or “animal detectors,” focusing processing on features that are associated with those categories.

What then directs where attention goes, if it works in this radically distributed interactive fashion? If we have a system that cascades its information from subsystem to subsystem so promiscuously that we lose track of which signals are feedforward and which are feedback, can we still have something coherent enough to be called “attention”? Rather than conceiving of attention as a “spotlight” directed by a central executive, a more scientifically sound approach may be to conceive of attention as the emergent result of biased competition among multiple partially active representations (Desimone and Duncan, 1995). Rather than assuming that the focus of mental activity at any one point in time somehow derives from one source, like the central processing unit of a computer, perhaps it instead derives from myriad sources. Some of these sources are goals and biases from neighboring neural subsystems. Some of them are biases from immediately perceivable environmental constraints. Some of them are biases from signals delivered by other people in the environment. At longer timescales, some of these biases are social norms and cultural constraints. At even longer timescales, some of these sources are evolutionary influences. The density of perceptual acuity at a particular moment in time – the sense of “who we are” and “what we’re about” at that moment – is something that emerges non-linearly out of the complex interactions among innumerable informational biases competing and cooperating in real time (Spivey, 2013).

Cascaded interaction spreads

With different sensory, cognitive, and motor systems continuously biasing one another in real time, there is no point in time during which a given subsystem is processing its input in a context-free manner. There will always have been some form of contextual bias that was busy influencing the given subsystem immediately before some new afferent sensory input enters it. If continuous distributed interactions between sensory systems make vision no longer an encapsulated module, and audition no longer an encapsulated module, then continuous distributed interactions among cognitive processes and motor processes make cognition no longer a module that is separate from

action – hence, embodied cognition. In fact, given the millisecond timescale at which various motor movements continuously update the sensory input, which continuously updates cognitive processes, which continuously update the ongoing motor commands, perhaps those external actions themselves may not even be informationally encapsulated from cognition. As Sue Hurley (1998, p. 3) put it: “if internal relations can qualify as [representational] vehicles, why not external relations? Given a continuous complex dynamic system of reciprocal causal relations between organism and environment, what in principle stops the spread? The idea that [representational] vehicles might go external takes the notion of distributed processing to its logical extreme.”

A famous example of cognitive processes “going external” comes from Kirsh and Maglio’s (1994) Tetris experiments. They found that novice Tetris players tended to perform something equivalent to “mental rotation” (à la Shepard and Metzler, 1971) of the shapes in the game to determine where to place them. By contrast, expert Tetris players offloaded that cognitive operation onto their environment by using the fast rotate-button frequently. This allowed the computer interface in front of a participant to perform the cognitive operation of image rotation and the neural system in their skull to perform the cognitive operation of perceptual matching. The result was that these experts were significantly faster and more accurate than the novices.

Skeletal motor movements are a useful way to perform cognitive operations, such as pressing keys on an interactive computer interface. But there is a far more ubiquitous motor movement, happening about three times per second, that performs cognitive operations during your entire waking life, no matter where you are, or what you are doing: eye movements. Ballard, Hayhoe, Pook, and Rao (1997) demonstrated that a given eye fixation can function like a “pointer” (in a content-addressable computer memory). Rather than forming neural representations of complex visual objects in memory while viewing a scene, people often simply maintain spatial locations in memory, and send the eyes to those locations to access the “content” in those “addresses.” Essentially, people exhibit a strong tendency to use one’s environment as an external memory store (see also, O’Regan, 1992).

Thus, on the timescale of a few hundred milliseconds, eye movements are changing how the environment impacts your sensors, which changes how you cognize your environment, which changes the next eye movement, which changes the next sensory input, and so on. This is a recurrent causal loop that cannot be unraveled to find the chicken versus the egg. Half of the data transformations that constitute an organism’s attention are actually happening outside the body, in how the body’s movements have altered how light projects onto the retinas. So much so that one could be tempted to suggest that much of your “visual experience” is itself happening in the space around you, rather than solely inside your brain (O’Regan and Noë, 2001; see also Clark and Chalmers, 1998).

Eye movements and the perception-action loop

It has long been understood that there is a close link between visual attention and eye movements. Even when an experimental participant fixates a central dot on a computer screen and covertly directs attention to the periphery for several hundred milliseconds – as is often done in cognitive psychology experiments (Posner, Snyder and Davidson, 1980) – oculomotor systems of the brain are essentially programming an eye movement and then holding back from executing it, and this process is part and parcel of visual attention (Corbetta, 1998; Deubel and Schneider, 1996). In fact, neurons in parietal cortex receive feedback from oculomotor regions signaling an upcoming saccade, such that they are able to shift their receptive fields to the new upcoming region in the visual field and begin responding to a visual stimulus that is not yet in their classical receptive field (Colby, Duhamel, and Goldberg, 1996). This prospective responsiveness to visual

input, in anticipation of a saccade, clearly blurs the line between the motor programming of a saccade planning and the process of covert visual attention. As a result of this close link between these two processes, the vast majority of covert shifts of attention are immediately followed by an eye movement to that same location. Thus, eye movements are quite literally a physical embodiment of visual attention. They allow even a subtle cognitive bias about what is goal-relevant in the environment to be converted – in just a couple hundred milliseconds – into a powerful perceptual bias for what is dominating visual processing, via the high-resolution fovea.

In this way, not only are eye movements highly useful for the experimenter, as a record of what is drawing attention at any moment, but they are also highly useful for the organism itself. A different pattern of eye movements on the same scene will not only *reveal* a different thought process about that environment (Yarbus, 1967), it can *cause* a different thought process about that environment. For example, just as recording eye movements during mechanical problem-solving has provided a deeper understanding of mechanical reasoning (Hegarty and Just, 1993; Rozenblit, Spivey, and Wojslawowicz, 2002), it has also provided inspiration for improvement of training with technical devices (Hegarty, 2005).

Even high-level conceptual insights can be jump-started, or missed entirely, by different eye movement patterns on a diagram associated with an insight problem. People who are 30 seconds away from solving a diagram-based version of Karl Duncker's famous tumor-and-lasers radiation problem tend to make a characteristic pattern of eye movements on the diagram (Grant and Spivey, 2003). Those who are 30 seconds away from *giving up* on the problem exhibit less of that eye-movement pattern. Interestingly, this pattern of eye movements was not merely an indicator to the experimenters that a person was about to solve the problem, but that pattern of eye movements was actually assisting the person in arriving at the solution. In their second experiment, Grant and Spivey subtly animated the diagram in a way that unconsciously induced that pattern of eye movements, and it doubled the proportion of people solving the problem. Thomas and Lleras (2007) followed up this work with a version of the task where participants were explicitly instructed to move their eyes in a pattern across the diagram. Participants who moved their eyes in the pattern that produced converging lines on the tumor exhibited a higher rate of finding the solution. As one might expect, based on the overlap between attentional mechanisms and eye-movement mechanisms, even when participants don't move their eyes at all, but instead move their attention covertly in this converging-lines pattern, performance on this insight problem is improved (Thomas and Lleras, 2009). Based on results like these, it may be useful to treat the relation between organism and environment as not only the place where perception and action take place (e.g. Gibson, 1979), but also the place where cognition takes place.

The embodiment of attention

Cognitive science has a long history of drawing inspiration from the computer metaphor of the mind and placing the bulk of its emphasis on how external stimuli influence mental processing, but this is only one half of the story. The other half, of equal importance, is how mental processing influences external stimuli. When attention gets physically embodied in motor movements (even subtle and brief ones like eye movements and other muscle twitches), those movements change the way the environment impacts our sensors in ways that abide by continuous physical laws (Gibson, 1979; Turvey, 1992; Chemero, 2009). The result is that while the environment is catalyzing events in the brain, the brain is simultaneously catalyzing events (i.e. motor movements) in the environment. This autocatalytic loop, whereby the brain and the environment produce an emergent phenomenon called cognition, steers our understanding of

the mind away from the formal logical computer metaphor, where genuine autocatalysis is not logically possible. And it is radically changing how we conceptualize joint action when two people are sharing an environment, and intermingling their perception-action loops (Dale, Fusaroli, Duran, and Richardson, 2013; Spivey, 2012). If we acknowledge that attention in particular, and the mind in general, is an emergent property of an embodied brain interacting with its environment, then the future of cognitive science will require a complex dynamical systems approach to cognition (Spivey, 2007), drawing insights from embodied cognition (Barsalou, 1999), ecological psychology (Turvey and Carello, 1995), complexity theory (Van Orden, Holden, and Turvey, 2003), computational neuroscience (Kello, 2013), and robotics (Pezzulo *et al.*, 2011).

References

- Allport, A. (1989). Visual attention. In M. I. Posner (Ed.), *Foundations of cognitive science* (pp. 631–82). Cambridge, MA: MIT Press.
- Ballard, D. H., Hayhoe, M. M., Pook, P. K., and Rao, R. P. (1997). Deictic codes for the embodiment of cognition. *Behavioral and Brain Sciences*, 20(4), 723–42.
- Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, 22(4), 577–660.
- Broadbent, D. E. (1958). *Perception and communication*. New York: Oxford University Press.
- Chemero, A. (2009). *Radical embodied cognitive science*. Cambridge, MA: MIT press.
- Chiu, E. M., and Spivey, M. J. (2011). Linguistic mediation of visual search: effects of speech timing and display. In B. Kokinov, A. Karmiloff-Smith, and N. J. Nersessian (Eds.), *European perspectives on cognitive science*. Sofia: New Bulgarian University Press.
- Clark, A., and Chalmers, D. (1998). The extended mind. *Analysis*, 58(1), 7–19.
- Colby, C. L., Duhamel, J. R., and Goldberg, M. E. (1996). Visual, presaccadic, and cognitive activation of single neurons in monkey lateral intraparietal area. *Journal of Neurophysiology*, 76(5), 2841–52.
- Coles, M., Gratton, G., Bashore, T., Eriksen, C., and Donchin, E. (1985). A psychophysiological investigation of the continuous flow model of human information processing. *Journal of Experimental Psychology: Human Perception and Performance*, 11, 529–53.
- Corbetta, M. (1998). Frontoparietal cortical networks for directing attention and the eye to visual locations: Identical, independent, or overlapping neural systems? *Proceedings of the National Academy of Sciences of the United States of America*, 95(3), 831–38.
- Dale, R., Fusaroli, R., Duran, N., and Richardson, D. C. (2013). The self-organization of human interaction. *Psychology of Learning and Motivation*, 59, 43–95.
- Daugman, J. G. (1993). Brain metaphor and brain theory. In E. L. Schwartz (Ed.), *Computational neuroscience* (pp. 9–18). Cambridge, MA: MIT Press.
- Desimone, R., and Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, 18(1), 193–222.
- Deubel, H., and Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research*, 36(12), 1827–37.
- Driver, J., and Spence, C. (2000). Multisensory perception: Beyond modularity and convergence. *Current Biology*, 10(20), R731–35.
- Duncan, J., and Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological Review*, 96(3), 433–58.
- Fodor, J. (1983). *The modularity of mind*. Cambridge, MA: MIT Press.
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.
- Gold, J., and Shadlen, M. (2000). Representation of a perceptual decision in developing oculomotor commands. *Nature*, 404, 390–94.
- Grant, E. R., and Spivey, M. J. (2003). Eye movements and problem solving guiding attention guides thought. *Psychological Science*, 14(5), 462–66.
- Hegarty, M. (2005). Multimedia learning about physical systems. In R. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 447–65). New York: Cambridge University Press.
- Hegarty, M., and Just, M. A. (1993). Constructing mental models of machines from text and diagrams. *Journal of Memory and Language*, 32(6), 717–42.

- Hommel, B., Müsseler, J., Aschersleben, G., and Prinz, W. (2001). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences*, 24(5), 849–78.
- Hurley, S. (1998). Vehicles, contents, conceptual structures, and externalism. *Analysis*, 58, 1–6.
- Jordan, J. S. (1999). Cognition and spatial perception: Production of output or control of input? *Advances in Psychology*, 129, 69–90.
- Kawato, M. (1999). Internal models for motor control and trajectory planning. *Current Opinion in Neurobiology*, 9(6), 718–27.
- Kello, C. T. (2013). Critical branching neural networks. *Psychological Review*, 120(1), 230–54.
- Kirsh, D., and Maglio, P. (1994). On distinguishing epistemic from pragmatic action. *Cognitive Science*, 18(4), 513–49.
- Lachter, J., Forster, K. I., and Ruthruff, E. (2004). Forty-five years after Broadbent (1958): Still no identification without attention. *Psychological Review*, 111(4), 880–913.
- Lupyan, G., and Spivey, M. J. (2008). Perceptual processing is facilitated by ascribing meaning to novel stimuli. *Current Biology*, 18(10), R410–12.
- Macaluso, E., Frith, C. D., and Driver, J. (2000). Modulation of human visual cortex by crossmodal spatial attention. *Science*, 289(5482), 1206–8.
- McClelland, J. (1979). On the time relations of mental processes: An examination of systems of processes in cascade. *Psychological Review*, 86, 287–330.
- McGurk, H., and MacDonald, J. (1976). Hearing lips and seeing voices. *Nature*, 264(5588), 746–48.
- Moran, J., and Desimone, R. (1985). Selective attention gates visual processing in the extrastriate cortex. *Science*, 229(4715), 782–84.
- Motter, B. C. (1993). Focal attention produces spatially selective processing in visual cortical areas V1, V2, and V4 in the presence of competing stimuli. *Journal of Neurophysiology*, 70(3), 909–19.
- Nakayama, K., and Silverman, G. H. (1986). Serial and parallel processing of visual feature conjunctions. *Nature*, 320(6059), 264–65.
- Olds, E. S., Cowan, W. B., and Jolicoeur, P. (2000). The time-course of pop-out search. *Vision Research*, 40(8), 891–912.
- O'Regan, J. K. (1992). Solving the “real” mysteries of visual perception: The world as an outside memory. *Canadian Journal of Psychology*, 46(3), 461–88.
- O'Regan, J. K., and Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, 24(5), 939–72.
- O'Reilly, R. C., Wyatte, D., Herd, S., Mingus, B., and Jilk, D. J. (2013). Recurrent processing during object recognition. *Frontiers in Psychology*, 4(124).
- Pezzulo, G., Barsalou, L. W., Cangelosi, A., Fischer, M. H., McRae, K., and Spivey, M. J. (2011). The mechanics of embodiment: A dialog on embodiment and computational modeling. *Frontiers in Psychology*, 2(5).
- Posner, M. I., Snyder, C. R., and Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, 109(2), 160–74.
- Rozenblit, L., Spivey, M., and Wojslawowicz, J. (2002). Mechanical reasoning about gear-and-belt systems: Do eye movements predict performance? In M. Anderson, B. Meyer, and P. Olivier (Eds.), *Diagrammatic representation and reasoning*. Berlin: Springer.
- Sekuler, R., Sekuler, A. B., and Lau, R. (1997). Sound alters visual motion perception. *Nature*, 385(6614), 308.
- Shams, L., Kamitani, Y., and Shimojo, S. (2000). What you see is what you hear. *Nature*, 408(6814), 788.
- Shepard, R., and Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, 171(3972), 701–3.
- Spivey, M. J. (2007). *The continuity of mind*. New York: Oxford University Press.
- (2012). The spatial intersection of minds. *Cognitive Processing*, 13, 343–46.
- (2013). The emergence of intentionality. *Ecological Psychology*, 25(3), 233–39.
- Spivey, M. J., Tyler, M. J., Eberhard, K. M., and Tanenhaus, M. K. (2001). Linguistically mediated visual search. *Psychological Science*, 12(4), 282–86.
- Thomas, L. E., and Lleras, A. (2007). Moving eyes and moving thought: On the spatial compatibility between eye movements and cognition. *Psychonomic Bulletin & Review*, 14(4), 663–68.
- (2009). Covert shifts of attention function as an implicit aid to insight. *Cognition*, 111(2), 168–74.
- Treisman, A. M. (1969). Strategies and models of selective attention. *Psychological Review*, 76(3), 282–99.
- Treisman, A. M., and Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, 12(1), 97–136.
- Turvey, M. T. (1992). Affordances and prospective control: An outline of the ontology. *Ecological Psychology*, 4(3), 173–87.

- Turvey, M. T., and Carello, C. (1995). Some dynamical themes in perception and action. In R. F. Port and T. van Gelder (Eds.), *Mind as motion: Explorations in the dynamics of cognition*. Cambridge, MA: MIT Press.
- van der Heijden, A. H. C. (1996). Perception for selection, selection for action, and action for perception. *Visual Cognition*, 3, 357–61.
- Van Orden, G. C., Holden, J. G., and Turvey, M. T. (2003). Self-organization of cognitive performance. *Journal of Experimental Psychology: General*, 132(3), 331–50.
- Van Rullen, R., and Thorpe, S. (2001). Is it a bird? Is it a plane? Ultra-rapid categorization of natural and artificial objects. *Perception*, 30, 655–68.
- Wolfe, J. M. (1998). What can 1 million trials tell us about visual search? *Psychological Science*, 9(1), 33–39.
- Yarbus, A. L. (1967). *Eye movements and vision*. New York: Plenum press.

EMBODIED REMEMBERING

John Sutton and Kellie Williamson

Introduction: the diversity of embodied remembering

Experiences of embodied remembering are familiar and diverse. We settle bodily into familiar chairs or find our way easily round familiar rooms. We inhabit our own kitchens or cars or workspaces effectively and comfortably, and feel disrupted when our habitual and accustomed objects or technologies change or break or are not available. Hearing a particular song can viscerally bring back either one conversation long ago, or just the urge to dance. Some people explicitly use their bodies to record, store, or cue memories. Others can move skilfully, without stopping to think, in complex and changing environments thanks to the cumulative expertise accrued in their history of fighting fires, or dancing, or playing hockey. The forms of memory involved in these cases may be distinct, operating at different timescales and levels, and by way of different mechanisms and media, but they often cooperate in the many contexts of our practices of remembering.

We share Maxine Sheets-Johnstone's suspicion that labels like "embodied" and "embodiment" sometimes function as "lexical band-aids" to cover residual theoretical gaps or wounds (2009a, p. 375) – after all, what else could cognition and remembering be, if not embodied? But we use the terms to mark the mundane but fascinating range of everyday experiences which the terms naturally cover. Though it is true that writers use "embodied memory" in very different ways, this is not necessarily a sign of endemic confusion. Given the dramatic variety of the relevant phenomena, embodied memory is appropriately of interest in both basic and applied studies of many distinctive topics – dance and sport, trauma and therapy, emotion and expertise, to mention just a few. It is a topic which rightly spans not only the range of the cognitive sciences, but also social science and the humanities. Two-way benefits could flow between theory and practice: academic discussions of "embodied cognition," which can sometimes be curiously abstract or anecdotal, could fruitfully engage with and in turn contribute to rich bodies of lore and expertise among practitioners of bodily skills and well-developed research traditions in fields like sports science, music psychology, and dance cognition.

Human beings are unusual in the variety of ways we relate to our history. Past events can be explicitly and consciously recollected, or can have more implicit influences on body, mind, and action. As well as the many respects in which the cumulative effects of the past drive our biology and our behavior, we also have the peculiar capacity to think *about* our histories. We

can remember cooking a particular dish on a specific occasion for just that group of friends, though of course such memories are fallible. I remember cooking that meal *because* I did so, and this past experience is itself also the *object* of my thought. But we can also remember *how* to cook, as we show simply by doing so. In the latter case, accumulated experiences are actively embodied in actions. I need not explicitly recollect any specific past events, or even recognize that I am remembering, unless my smooth coping is disrupted. As Edward Casey puts it, such memory is intrinsic to the body: “because it re-enacts the past, it need not represent it” (1987, pp. 147, 178).

Across different theoretical traditions, more implicit or habitual forms of body memory are thus distinguished from “personal” or “episodic” or “autobiographical” remembering (Sutton, Harris, and Barnier, 2010). Below we explore the differences between these forms of memory: without committing to any view on whether they are parts of distinct memory “systems,” we suggest that by initially distinguishing them we can address intriguing questions about the many ways in which they interact. Any discussion of our topic has to be able to deal with the variety of these phenomena. It would be misleading to restrict an account of embodied remembering either to the realm of meaning and conceptualization, or in contrast to embodied skills and habits alone.

The idea that explicit personal recall, when I remember particular past events, is a close ally of remembering how to perform bodily actions was stated powerfully by Bartlett (1932, pp. 201–2).

Suppose I am making a stroke in a quick game, such as tennis or cricket ... When I make the stroke I do not, as a matter of fact, produce something absolutely new, and I never merely repeat something old. The stroke is literally manufactured out of the living visual and postural “schemata” of the moment and their interrelations. I may say, I may think that I reproduce exactly a series of text-book movements, but demonstrably I do not; just as, under other circumstances, I may say and think that I reproduce exactly some isolated event which I want to remember, and again demonstrably I do not.

In his radical constructivism, Bartlett suggests that the unique contextual processes of retrieval sculpt, not just the form or expression of a memory, but its very content. Just as the dynamic, on-the-fly embodied production of another successful backhand in tennis brings about a shot that may be familiar in type but is “absolutely new” in detail, so in remembering events my changing beliefs, interests, and motivations select and filter out materials to construct versions of the past (Saito, 2000; Middleton and Brown, 2005; Winter, 2012). Like Bartlett, we treat remembering as itself an embodied skill. In dynamic self-organizing psychobiological systems like us, embodiment brings transformation.

A fuller treatment of our topic would include a section on the history of embodied remembering, showing that embodiment is a surprisingly pervasive theme, from the longer time frames studied in cognitive archaeology (Donald, 1991; Jones, 2007; Sutton, 2008), through the intense attention offered to bodily aspects of memory and self by Descartes and Locke (Reiss, 1996; Sutton, 1998), to the key theoretical works of Nietzsche, Freud, the pragmatists James and Dewey, and the major phenomenologists Bergson (1991) and Merleau-Ponty (1962). But we can pick up one historical thread here by noting that some of Locke’s remarks on memory, place, and embodied context were cited by Godden and Baddeley (1975) in one of the most striking experimental studies of embodied memory in modern cognitive psychology: divers who learned material underwater (in open water sites near Oban in Scotland) had better memory

when tested underwater, while material learned on dry land was recalled better on dry land. If the context-dependence of memory, as they argued, is “robust enough to affect normal behaviour and performance away from the laboratory,” then the location, state, and nature of our bodies both at the time of the original experience and at the time of later retrieval drive what and how we remember. Mainstream psychologists have long been systematically studying the context-dependence of memory (Tulving and Thomson, 1971; Smith and Vela, 2001). This paved the way for a concerted movement, arising in the 1980s and 1990s from within the cognitive sciences, to study practical aspects of everyday memory in the wild (Neisser, 1978, 1997). Updating both Bartlett’s constructivism and his vision of a social and cultural psychology of memory, cognitive theorists drew on connectionism and on Vygotskian developmental psychology, and at the same time found experimental and institutional space for the rapid expansion of work on autobiographical memory and self in real-world contexts (Conway, 2005; Sutton, 2009a; Fivush, 2011). These strands of the recent history of the sciences of memory are perhaps sometimes neglected by writers on embodied cognition in general, in their urgency to paint the new paradigm as a radical break from the bad old days of rigid cognitivist individualism (Glenberg, 1997; Brockmeier, 2010; Glenberg, Witt, and Metcalfe, 2013). Some areas of memory science do certainly retain neurocentric tendencies, treating body and world either as merely external influences on the true internal memory processes, or as just the objects of memory: but pluralist alternatives have long been available by which to thematize the multiple resources of everyday ecologies of memory (Engel, 1999; Conway and Pleydell-Pearce, 2000; Siegel, 2001; Welzer and Markowitsch, 2005). We illustrate this by examining autobiographical memory and habitual or skill memory in turn: in each case, we suggest not only that the forms of remembering involved are in various respects “embodied,” but also that there are intricate relationships between them.

Embodied autobiographical memory

Recent psychological studies of autobiographical remembering emphasize that tracking the past is not necessarily its key function. Remembering also plays important and heavily context-sensitive roles in maintaining and renegotiating self-narratives, in promoting social relations, and in directing future action (Bluck, Alea, Habermas, and Rubin, 2005); recent work especially stresses the future-oriented role of memory in guiding simulations of possible future events (Schacter and Addis, 2007; Boyer, 2009). Personal narratives, social interactions, and future planning are often expressed and embodied in rich social and material settings. So autobiographical recall is embodied in that it is often *for* action and communication (Glenberg, 1997; Middleton and Brown, 2005), even though the specific past experiences I now remember may be long gone and may have left little or no trace on my current environment.

As well as being a conduit for sharing and renegotiating experience, the body can also be a cue or trigger for personal memory experiences, where this can occur either deliberately or unintentionally. The involuntary activation of a particular memory by way of sensory triggers is most commonly associated with smells and tastes, as classically in Proust (Berntsen, 2009). But even Proust’s narrator is just as powerfully drawn back into explicit recollection by way of the body’s familiarity with certain places – rooms, the location of furniture, the angle of the sunlight, the orientation of the body on the bed (see Casey, 1987, pp. 169–78). The mnemonic significance of objects, places, and environments operates by way of temperature or interoceptive bodily sensations such as hunger, as well as through encounters with specific remembered landmarks and locations. There can be different relations between familiarity and recollection. The pre-reflective sense of embodied intimacy with a setting may coexist or merge

both with culturally anchored schemata that suggest what usually happens here according to the social frameworks of memory, and with the more precise evocation of particular located personal experiences (Halbwachs, 1925/1992; de Certeau, 1984; Habermas and Paha, 2002; Hill, 2011). More deliberate bodily anchors for personal memory include using the body to store information or evocative cues temporarily, as in writing a phone number on one's palm, or indelibly, as in the "system" of tattoos and other traces laboriously and fallibly constructed by Leonard in *Memento* (Sutton, 2009b). For those without Leonard's amnesic difficulties, bodily movements such as gestures can be an effective complement to other forms of thinking, remembering, and communicating, often stabilizing or anchoring complex concepts so as to facilitate communication or reconsideration (Hutchins, 2005, 2010; Streeck, Goodwin, and LeBaron, 2012; Bietti and Galiana Castello, 2013).

Further claims about the body's influence on autobiographical recall come from cognitive psychological research on the importance of sensory and motor functions in memory. One tradition examines enhanced memory for actions performed by the subject herself, compared with observing actions being performed by others (Zimmer *et al.*, 2001). Other experimental research addresses embodiment in the form of facial expression and body posture, as discussed in the chapter by Dijkstra and Zwaan (Chapter 28, this volume). Future work might extend these methods to examine the mnemonic significance of those culturally specific postures by which social norms and distinctions are incorporated (Connerton, 1989, pp. 73–74).

In addition to these ways in which bodily processes influence autobiographical memory, we can also make sense of the stronger idea that the body just is, or perhaps is the vehicle of, such explicit recall. In developing their systematic causal theory of declarative memory, C. B. Martin and Max Deutscher (1966) began by outlining a striking case in which remembering a particular event is actually constituted by certain bodily movements. Consider, they asked us,

the case where some swimming is an example of remembering and not, as is usual, an example of remembering how. Suppose that someone has never dog-paddled. He is not good at visualization and has never learned any words which would describe swimming. His method of representing the one time at which he saw a man dog-paddle is his actually doing the dog-paddle stroke. We can imagine him trying to remember the curious action that the man went through in the water. He cannot describe it, and cannot form any picture of it. He cannot bring it back. He gets into the water, experimenting a little until suddenly he gets it right and exclaims, "Aha, that's it!"

(Martin and Deutscher, 1966, pp. 161–62).

Here the body is the very vehicle of episodic memory. Indeed, the recall of personally experienced events even in more typical contexts often has a kinesthetic component. As I am telling you about a difficult conversation at work, or recollecting my pleasurable walk in the park the other day, specific movement tendencies may arise, in addition to other sensory-perceptual, spatial, and emotional detail (Rubin 2006). I may actually move my head and eyes, or partly reinstate a pattern of gestures in remembering the embodied alignment of that earlier conversation; or I may merely retouch or alight briefly again on the specific combination of physical warmth and affective comfort I felt during that summer stroll. When those who play music or sport pick up a household tool and quietly enact a momentary shadow performance, or simply run a fragment of air guitar or a backhand down the line, they are sometimes just remembering how to play. But on other occasions, perhaps especially in joyous re-enactment of pleasurable performance, or when something hasn't been quite right, they are also remembering a particular

incident or episode: in the latter case, merging that embodied autobiographical memory with an equally specific form of operative motor imagination, they can work in a more or less goal-directed fashion towards a refashioning of embodied style.

These phenomena are returning us to consideration of more habitual forms of embodied remembering. We suggest that both when remembering our past alone, and when talking together about shared experiences, there can be an iterative, mutually reinforcing play between personal memory and embodied habits or skills. The familiar actions involved in cooking or dancing, or in enjoying a conversation with old friends, are as Bartlett noted neither precise and mechanical repetitions, nor wholly unprecedented novelties. Cooking utensils which embody collective family memories, for example, also often elicit, more or less explicitly, specific personal and interpersonal memories: not just about what we used to do or would always do, but sometimes about particular family stories (Sutton and Hernandez, 2007; Shore, 2009).

Before scoring his second goal in the 1986 World Cup quarter-final against England, Diego Maradona ran through the defense, with his centre forward Jorge Valdano keeping pace alongside. As Valdano later told it, after the game Maradona apologized for not passing, even though at first he intended to: “Maradona explained that, as he neared the England goal, he remembered being in a similar situation against Peter Shilton seven years earlier at Wembley. In 1979 he had missed but, thinking about it now, he realised where he’d made his mistake. Maradona concluded that he didn’t need Valdano after all and could score by himself” (Winner, 2011, p. 23). Obviously Maradona’s success here relies on exquisitely honed bodily and technical skills. But he was also set apart from other players by effective decision making at unimaginable speed: here his choice draws directly on a specific past experience. Such precise use of episodic memory to dictate or sculpt present action is striking because it demonstrates the openness of our motor processes to fast, effortless top-down influence, and the conversion of personal memory into usable online form to feed bodily skill in real time. Such interanimation of skill or habit memory with personal memory is not always easy to notice: but, we suggest, it is a widespread feature of the practice of everyday life.

Embodied skill memory

In textbooks on memory in psychology and cognitive neuroscience, the topics discussed under the term “procedural memory” (memory for the performance of particular actions) sometimes focus primarily on lower-level phenomena of conditioning and associative learning (Eichenbaum and Cohen, 2001). This allows for coverage of the neuroanatomy of habit learning, and of the rapidly developing study of molecular mechanisms. Though dynamic, network-oriented neuroscience is increasingly devoted to examining interactions between distinct brain systems, it can sometimes be hard to see how these phenomena of procedural memory scale up to the kinds of habits and skills involved in embodied, culturally embedded human routines, performances, and rituals. Yet on initial description at least, embodied habits and skills do seem to share certain features with basic bodily responses to repeated experience. Consequently they too can appear to differ dramatically from other more explicit forms of memory: this is underlined by the apparent neural dissociation, such that some people with dense amnesia for specific events in their own history seem nonetheless to be able to learn new skills (Squire, 2004; but compare Stanley and Krakauer, 2013). Because the forms of memory seem so different, some have suggested that procedural memory is not a form of “memory” at all (Moyal-Sharrock, 2009), and others have argued that “memory” does not qualify as a coherent natural kind for scientific investigation (Michaelian, 2011). While we take the more ecumenical view that the various ways in which

history animates body and mind are interconnected, more embodied forms of memory do have features that sharply mark them as distinctive.

If I remember how to cook, ride a bike, or play a cover drive in cricket, I have engaged in practice and training: these embodied memories derive from many repeated experiences rather than one. There is no single, specific past event which causes my current activity, as there is in episodic memory, nor do I need be aware at all of any previous performances or of the historical source of my know-how (indeed, it is often crucial that I am not aware of anything beyond the present context) (Sutton, 2007). In his phenomenological study, Edward Casey offers a working definition of “habitual body memory”: it is “an active immanence of the past in the body that informs present bodily actions in an efficacious, orienting, and regular manner” (1987, p. 149; see also Casey, 2000; Connerton, 1989, p. 72; Summa, Koch, Fuchs, and Müller, 2012). These are not rote mechanical processes which simply reproduce past performances; rather, such body memory operates flexibly, as the practitioner adapts and adjusts to changing circumstances, subtly modifying her responses to fit the needs of the moment. Some theorists have sought to downgrade “habits” to more reflex-like status. For Ryle, “mere habits” are single-track dispositions implemented automatically, unlike the flexible exercise of practical intelligence (1963, pp. 41–50, 126–30). Others place habits within the realm of intentional action, noting the role of care and attention; no matter how effectively we have grooved our expertise as drivers, Brett points out, “the habit of paying attention to the road is one of the necessary ingredients in being a good driver” (1981, pp. 365–66; see also Pollard, 2006). But it is hard to pin down just what kinds of attention or awareness are in play here.

Although skills, habits, and embodied movement capacities are often easy to initiate spontaneously in the right context, they are difficult to think through consciously, and to articulate verbally. Some coaches and teachers are better than others at finding instructions, metaphors, or nudges to help novice and expert practitioners, and some critics and commentators can describe flowing performance with more striking explicit descriptions. Learning by apprenticeship is a central part of human socialization, and does sometimes involve explicit description and some decomposition of tasks (Sterelny, 2012; Sutton, 2013). But talking well about embodied skills is, in most contexts, an entirely different skill from the first-order capacities themselves, which rely more on complex pattern recognition and on other coordinated perceptual-motor-memory processes which no-one really understands (Sutton, 2007). For this reason, practitioners and theorists alike often draw sharp lines between embodied skill memory, on the one hand, and more “cognitive” or “mindful” processes: Hubert Dreyfus, for example, argues that “mindfulness is the enemy of embodied coping” (2007, p. 353; see also Ennen, 2003). Performers are all too aware that certain forms of reflection and thought can disrupt their skilful action, and often talk of relying on their body memory alone, and allowing automated responses to flow intuitively. But this does not mean that one is unconscious when actively remembering how to do something: in different contexts, various forms of kinetic or kinesthetic awareness or circumspection allow for the ongoing monitoring of skilful performance (Sheets-Johnstone, 2003; Wheeler, 2005, pp. 131–43). Talk about embodied skills can be analogical and indirect, with groups of experts often evolving local responses to the challenges of languaging experience, often “beyond the easy flow of everyday speech” (Sheets-Johnstone, 2009b, p. 336; see Candau, 2010 for the case of finding words for olfactory experience and thus sharing memory for smells). It is a mistake to treat embodied memory as so entirely intuitive as to be outside the psychological realm, for this is to reinforce dichotomies between acting and thinking, and between body and mind, which need to be thoroughly dismantled to achieve better understanding of these complex phenomena (Montero, 2010; Sutton, McIlwain, Christensen, and Geeves, 2011).

Accounts of body memory can, further, address the bodily systems of interoception and affect which partly ground our deep feelings of familiarity in our world, and our awareness of self and time (Damasio, 2003). They can extend the taxonomy to include situational and intercorporeal memory, covering our spatial awareness and our implicit sense of a history of embodied experiences with other people (Fuchs, 2012, pp. 13–15), and the way the body carries cultural norms and tastes, by way of incorporated techniques, practices, or ceremonies (Bourdieu, 1977, pp. 72–87; Connerton, 1989, pp. 79–88; Strathern, 1996). Questions about the bodily nature of memory are under intense investigation in the cognitive anthropology of religion and ritual behavior, where varying levels of emotional arousal are seen, on different theories, as grounding different kinds of memory and thus dictating the required frequency of religious ritual performance (Whitehouse, 2005; Czachesz, 2010). Other writers focus on memory for pain and trauma, and cases in which the usual pre-reflective nature of embodied memory breaks down (Casey, 1987, pp. 154–57; Haaken, 1998; Fuchs 2012, pp. 16–18). We now briefly mention two further lines of research about the body and memory.

In a phenomenological investigation of certain kinds of “bodily micromovements” which she calls “ghost gestures,” Elizabeth Behnke (1997) analyzes a range of “tendencies to movement” such as “persisting patterns of trying, bracing, freezing” which persist as “the effective presence of the past,” the inadvertent residues of embodied activities (such as digging in the garden) or specific historical patterns of comportment (such as hugging the computer). Signature patterns of movement, posture, and gesture are often coupled with particular modes of affective experience and expression: as Behnke argues, they can sometimes be opened up to kinesthetic awareness, as we counter our easy sensorimotor amnesia, and find ways of noticing and perhaps shifting our more rigid or fused bodily habits (Behnke, 1997, 2008; see also Samudra, 2008; Shusterman, 2011; McIlwain and Sutton, 2014).

More dramatic pathologies of memory arise in the amnesias and dementias: in some cases embodied remembering can here act as a partial counter to a gradual or sudden loss of explicit memory. As explicit access to particular past experiences comes under threat, and with it the possibility of incorporating distinct episodes into roughly coherent life narratives, other ways of stabilizing or inhabiting a familiar world become more salient. The fictional case of Leonard in *Memento*, as we noted, dramatizes a reliance on both habits and procedures and on systems of embodied or externalized traces (Sutton, 2009b). In real cases of dementia, the relation between explicit knowledge of one’s own past and the forms of bodily familiarity with one’s world can be complicated, though remembering how to do various tasks does often persist longer. The anthropologist Janelle Taylor argues that interpersonal care and mutual recognition can rest on broader patterns of shared activities than simply talking about particular past events and experiences: conversation, for example, involves tone, voice pattern, and turn-taking corporeal sequencing as much as the exchange of information (2008, pp. 326–28). As well as deploying compensatory social or material scaffolding to externalize access to lost information (Drayson and Clark, in press), people experiencing the early stages of dementia may still rely on practical, situational familiarity with environments, objects, and sequences of bodily actions in buffering themselves from the immediate effects of decline in explicit memory.

But some of the most powerful empirical and ethnographic studies of embodied skill memory have been undertaken in the context not of deficit and struggle but of extraordinary or expert capacities. In music, concert pianist Gabriela Imreh collaborated with cognitive psychologist Roger Chaffin and colleagues in long-term experimental studies of the precise stages by which she memorized Bach’s *Italian Concerto* (Chaffin, Imreh, and Crawford, 2002; Geeves, Christensen, Sutton, and McIlwain, 2008). In a quite distinctive musical and theoretical register, David Sudnow documented the often agonizing process of learning improvisational jazz piano:

in gradually remembering how to find ways round the keyboard and the ongoing musical piece in a flowing rather than disjointed way, Sudnow has to incorporate an open-ended but constrained repertoire of possible muscular and affective patterns of musical action (Sudnow, 2001). In studying embodied remembering in contemporary dance, Catherine Stevens and colleagues have investigated the interplay of verbal and movement phrases during rehearsal and in the process of choreographic creativity (Stevens, Malloch, McKechnie, and Steven, 2003; see also Sheets-Johnstone, 2012), while David Kirsh's team implemented mixed-method research on the memory functions of dancers' "marking" practices, when they re-embody or rehearse various fragmentary or partial movement forms (Kirsh, 2013).

Embodied memory in these contexts is firmly embedded in complex and idiosyncratic cultural settings, with unique social and historical backgrounds and norms. These cases remind us that by examining activities and practices of remembering, and in giving consideration to the role of bodily as well as neural resources, we also open up memory's public dimensions. Embodied remembering occurs in a social and material world in which objects and other people may support or transform the processes, form, and content of memory. If memory is embodied, it is also arguably situated and distributed.

In this chapter we have selectively introduced key themes from contemporary studies of the diverse forms of embodied remembering. We need to draw on philosophy of mind and action, phenomenology, psychology, cognitive neuroscience, anthropology, and performance studies if we are effectively to mesh conceptual, experimental, and ethnographic approaches to these diverse and complex phenomena. For this reason, in this short chapter we have sought to provide points of entry into these rich multidisciplinary literatures, hoping to encourage others to engage with these fascinating topics.

References

- Bartlett, F. (1932). *Remembering: A study in experimental and social psychology*. Cambridge: Cambridge University Press.
- Behnke, E. A. (1997). Ghost gestures: Phenomenological investigations of bodily micromovements and their intercorporeal implications. *Human Studies*, 20(2), 181–201.
- (2008). Interkinaesthetic affectivity: A phenomenological approach. *Continental Philosophy Review*, 41, 143–61.
- Bergson, H. (1991). *Matter and memory* (5th ed.; N. M. Paul and W. S. Palmer, Trans.). New York: Zone Books. (Orig. publ. 1896.)
- Berntsen, D. (2009). *Involuntary autobiographical memories: An introduction to the unbidden past*. Cambridge: Cambridge University Press.
- Bietti, L. M., and Galiana Castello, F. (2013). Embodied reminders in family interactions: Multimodal collaboration in remembering activities. *Discourse Studies*, 15(6).
- Bluck, S., Alea, N., Habermas, T., and Rubin, D. C. (2005). A tale of three functions: The self-reported uses of autobiographical memory. *Social Cognition*, 23(1), 91–117.
- Bourdieu, P. (1977). *Outline of a theory of practice*. Cambridge: Cambridge University Press.
- Boyer, P. (2009). What are memories for? Functions of recall in cognition and culture. In P. Boyer and J. Wertsch (Eds.), *Memory in mind and culture* (pp. 3–28). Cambridge: Cambridge University Press.
- Brett, N. (1981). Human habits. *Canadian Journal of Philosophy*, 11, 357–76.
- Brockmeier, J. (2010). After the archive: Remapping memory. *Culture & Psychology*, 16(1), 5–35.
- Candau, J. (2010). Shared memory, odours and sociotransmitters, or "Save the interaction!" *Outlines: Critical Practice Studies*, 2, 29–42.
- Casey, E. (1987). *Remembering: A Phenomenological Study*. Bloomington, IN: Indiana University Press.
- (2000). The ghost of embodiment: On bodily habitus and schemata. In D. Welton (Ed.), *Body and flesh* (pp. 207–25). Oxford: Blackwell.
- Chaffin, R., Imreh, G., and Crawford, M. (2002). *Practicing perfection: Memory and piano performance*. Mahwah, NJ: Erlbaum.

- Connerton, P. (1989). *How societies remember*. Cambridge: Cambridge University Press.
- Conway, M. A. (2005). Memory and the self. *Journal of Memory and Language*, 53(4), 594–628.
- Conway, M. A., and Pleydell-Pearce, C. W. (2000). The construction of autobiographical memories in the self-memory system. *Psychological Review*, 107(2), 261.
- Czachesz, I. (2010). Long-term, explicit memory in rituals. *Journal of Cognition and Culture*, 10, 327–39.
- Damasio, A. (2003). Feelings of emotion and the self. *Annals of the New York Academy of Sciences*, 1001, 253–61.
- de Certeau, M. (1984). *The practice of everyday life*. Berkeley: University of California Press.
- Donald, M. (1991). *Origins of the modern mind: Three stages in the evolution of culture and cognition*. Cambridge, MA: Harvard University Press.
- Drayson, Z., and Clark, A. (in press). Augmentation, agency, and the spreading of the mental state. *Consciousness and Cognition*.
- Dreyfus, H. L. (2007). The return of the myth of the mental. *Inquiry*, 50, 352–65.
- Eichenbaum, H., and Cohen, N. J. (2001). *From conditioning to conscious recollection: Memory systems of the brain*. New York: Oxford University Press.
- Engel, S. (1999). *Context is everything: The nature of memory*. New York: Freeman.
- Ennen, E. (2003). Phenomenological coping skills and the striatal memory system. *Phenomenology and the Cognitive Sciences*, 2, 299–325.
- Fivush, R. (2011). The development of autobiographical memory. *Annual Review of Psychology*, 62, 559–82.
- Fuchs, T. (2012). The phenomenology of body memory. In S. C. Koch, T. Fuchs, M. Summa, and C. Müller (Eds.), *Body memory, metaphor and movement* (pp. 9–22). Amsterdam: John Benjamins.
- Geeves, A., Christensen, W., Sutton, J., and McIlwain, D. J. F. (2008). Critical review of the book *Practicing perfection: Memory and piano performance*, by R. Chaffin, G. Imreh, and M. Crawford. *Empirical Musicology Review*, 3(3), 163–72.
- Glenberg, A. M. (1997). What memory is for. *Behavioral and Brain Sciences*, 20, 1–55.
- Glenberg, A. M., Witt, J. K., and Metcalfe, J. (2013). From the revolution to embodiment: 25 years of cognitive psychology. *Perspectives on Psychological Science*, 8, 573–85.
- Godden, D. R., and Baddeley, A. D. (1975). Context-dependent memory in two natural environments: On land and underwater. *British Journal of Psychology*, 66(3), 325–31.
- Haaken, J. (1998). *Pillar of salt: Gender, memory, and the perils of looking back*. New Brunswick, NJ: Rutgers University Press.
- Habermas, T., and Paha, C. (2002). Souvenirs and other personal objects: Reminding of past events and significant others in the transition to university. In J. D. Webster and B. K. Haight (Eds.), *Critical advances in reminiscence work* (pp. 123–38). New York: Springer.
- Halbwachs, M. (1925/1992). The social frameworks of memory. In L. Coser (Ed.), *On collective memory*. Chicago: Chicago University Press.
- Hill, S. (2011). Memory in place. *New Zealand Geographer*, 67, 16–20.
- Hutchins, E. (2005). Material anchors for conceptual blends. *Journal of Pragmatics*, 37, 1555–77.
- (2010). Imagining the cognitive life of things. In L. Malafouris and C. Renfrew (Eds.), *The cognitive life of things: Recasting the boundaries of the mind* (pp. 91–101). Cambridge: McDonald Archaeological Institute.
- Jones, A. (2007). *Memory and material culture*. Cambridge: Cambridge University Press.
- Kirsh, D. (2013). Embodied cognition and the magical future of interaction design. *ACM Transactions on Computer-Human Interaction*, 20(1), 30.
- Martin, C. B., and Deutscher, M. (1966). Remembering. *Philosophical Review*, 75(2), 161–96.
- McIlwain, D. J. F., and Sutton, J. (2014). Yoga from the mat up: How words alight on bodies. *Educational Philosophy and Theory*. doi:10.1080/00131857.2013.779216
- Merleau-Ponty, M. (1962). *Phenomenology of perception* (C. Smith, Trans.). London: Routledge. (Orig. publ. 1945.)
- Michaelian, K. (2011). Is memory a natural kind? *Memory Studies*, 4, 170–89.
- Middleton, D., and Brown, S. D. (2005). *The social psychology of experience: Studies in remembering and forgetting*. London: Sage.
- Montero, B. (2010). Does bodily awareness interfere with highly skilled movement?. *Inquiry*, 53, 105–22.
- Moyal-Sharrock, D. (2009). Wittgenstein and the memory debate. *New Ideas in Psychology*, 27, 213–27.
- Neisser, U. (Ed.) (1978). *Memory observed: Remembering in natural contexts*. New York: W. H. Freeman.
- (1997). The ecological study of memory. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 352(1362), 1697–1701.

- Pollard, B. (2006). Explaining actions with habits. *American Philosophical Quarterly*, 43, 57–68.
- Reiss, T. J. (1996). Denying the body? Memory and the dilemmas of history in Descartes. *Journal of the History of Ideas*, 57, 587–607.
- Rubin, D. C. (2006). The basic-systems model of episodic memory. *Perspectives on Psychological Science*, 1(4), 277–311.
- Ryle, G. (1963). *The concept of mind*. Harmondsworth: Penguin. (Orig. publ. 1949.)
- Saito, A. (Ed.) (2000). *Bartlett, culture and cognition*. Hove, East Sussex: Psychology Press.
- Samudra, J. K. (2008). Memory in our body: Thick participation and the translation of kinesthetic experience. *American Ethnologist*, 35, 665–81.
- Schacter, D. L., and Addis, D. R. (2007). On the constructive episodic simulation of past and future events. *Behavioral and Brain Sciences*, 30, 299–351.
- Sheets-Johnstone, M. (2003). Kinesthetic memory. *Theoria et Historia Scientiarum*, 7, 69–92.
- (2009a). Animation: The fundamental, essential, and properly descriptive concept. *Continental Philosophy Review*, 42, 375–400.
- (2009b). *The corporeal turn*. Exeter: Imprint Academic.
- (2012). From movement to dance. *Phenomenology and the Cognitive Sciences*, 11, 39–57.
- Shore, B. (2009). Making time for family: Schemas for long-term family memory. *Social Indicators Research*, 93, 95–103.
- Shusterman, R. (2011). Muscle memory and the somaesthetic pathologies of everyday life. *Human Movement*, 12, 4–15.
- Siegel, D. J. (2001). Memory: An overview, with emphasis on developmental, interpersonal, and neurobiological aspects. *Journal of the American Academy of Child & Adolescent Psychiatry*, 40(9), 997–1011.
- Smith, S. M., and Vela, E. (2001). Environmental context-dependent memory: A review and meta-analysis. *Psychonomic Bulletin & Review*, 8(2), 203–20.
- Squire, L. (2004). Memory systems of the brain: A brief history and current perspective. *Neurobiology of Learning and Memory*, 82, 171–77.
- Stanley, J., and Krakauer, J. W. (2013). Motor skill depends on knowledge of facts. *Frontiers in Human Neuroscience*, 7(503).
- Sterelny, K. (2012). *The evolved apprentice*. Cambridge, MA: MIT Press.
- Stevens, C., Malloch, S., McKechnie, S., and Steven, N. (2003). Choreographic cognition: The time-course and phenomenology of creating a dance. *Pragmatics and Cognition*, 11, 299–329.
- Strathern, A. (1996). *Body thoughts*. Ann Arbor: University of Michigan Press.
- Streeck, J., Goodwin, C., and LeBaron, C. (Eds.) (2012). *Embodied interaction: Language and body in the material world*. Cambridge: Cambridge University Press.
- Sudnow, D. (2001). *Ways of the hand: A rewritten account*. Cambridge, MA: MIT Press (Orig. publ. 1978.)
- Summa, M., Koch, S. C., Fuchs, T., and Müller, C. (2012). Body memory: An integration. In S. C. Koch, T. Fuchs, M. Summa, and C. Müller (Eds.), *Body memory, metaphor and movement* (pp. 417–44). Amsterdam: John Benjamins.
- Sutton, D., and Hernandez, M. (2007). Voices in the kitchen: Cooking tools as inalienable possessions. *Oral History*, 35, 67–76.
- Sutton, J. (1998). *Philosophy and memory traces: Descartes to connectionism*. Cambridge: Cambridge University Press.
- (2007). Batting, habit, and memory: The embodied mind and the nature of skill. *Sport in Society*, 10, 763–86.
- (2008). Material agency, skills, and history: Distributed cognition and the archaeology of memory. In L. Malafouris and C. Knappett (Eds.), *Material agency: Towards a non-anthropocentric approach* (pp. 37–55). Berlin: Springer.
- (2009a). Remembering. In M. Ayedede and P. Robbins (Eds.), *The Cambridge handbook of situated cognition*. Cambridge: Cambridge University Press.
- (2009b). The feel of the world: Exograms, habits, and the confusion of types of memory. In A. Kania (Ed.), *Memento* (pp. 65–86) (Philosophers on Film). London: Routledge.
- (2013). Skill and collaboration in the evolution of human cognition. *Biological Theory*, 8(1), 28–36.
- Sutton, J., Harris, C. B., and Barnier, A. J. (2010). Memory and cognition. In S. Radstone and B. Schwarz (Eds.), *Memory: Histories, theories, debates* (pp. 209–26). New York: Fordham University Press.
- Sutton, J., McIlwain, D. J. F., Christensen, W., and Geeves, A. (2011). Applying intelligence to the reflexes: Embodied skills and habits between Dreyfus and Descartes. *Journal of the British Society for Phenomenology*, 42(1), 78–103.

- Taylor, J. S. (2008). On recognition, caring, and dementia. *Medical Anthropology Quarterly*, 22, 313–35.
- Tulving, E., and Thomson, D. M. (1971). Retrieval Processes in recognition memory: Effects of associative context. *Journal of Experimental Psychology*, 87(1), 116–24.
- Welzer, H., and Markowitsch, H. (2005). Towards a bio-psycho-social model of autobiographical memory. *Memory*, 13(1), 63–78.
- Wheeler, M. (2005). *Reconstructing the cognitive world: The next step*. Cambridge, MA: MIT Press.
- Whitehouse, H. (2005). Emotion, memory, and religious rituals: An assessment of two theories. In K. Milton and M. Svasek (Eds.), *Mixed emotions: Anthropological studies of feeling* (pp. 91–108). Oxford: Berg.
- Winner, D. (2011). Dennis Bergkamp. *Blizzard: The Football Quarterly*, 1, 22–30.
- Winter, A. (2012). *Memory: Fragments of a modern history*. Chicago: University of Chicago Press.
- Zimmer, H. D., Cohen, R. L., Guynn, M. J., Engelkamp, J., Kormi-Nouri, R., and Foley, M. A. (2001). *Memory for action: A distinct form of episodic memory?* Oxford: Oxford University Press.

EMBODIMENT, COGNITION AND THE WORLD WIDE WEB

Paul R. Smart

Introduction

Embodied cognition forms part of an increasingly popular trend in the philosophy of mind and cognitive science which emphasizes the role played by extraneural and extracorporeal factors in human cognitive processing (Clark, 2008; Shapiro, 2011). It sits alongside a number of other areas of research, which we can collectively refer to as embodied, embedded, enactive and extended (4E) approaches to cognition. Although subtle differences exist between these approaches, what they have in common is a commitment to the idea that issues of material embodiment and environmental embedding play explanatorily significant roles in our understanding of human cognitive success.

The emphasis that 4E approaches place on extraneural and extracorporeal factors suggests that we should pay close attention to the various contexts in which cognition occurs. In this respect, the advent of the World Wide Web is of significant interest. The Web has rapidly emerged to transform the nature of many of our daily activities, and its growing popularity, in conjunction with the increasing ubiquity of Web-enabled devices and wireless networks, means that the Web now forms an increasingly prevalent part of the broader environmental context in which much of our daily thought and action is situated. Inasmuch as our cognitive profiles are shaped by information-processing loops that extend beyond the traditional biological borders of skin and skull, it is natural to wonder what effect this new form of technology-mediated information access will have on our individual cognitive profiles. If, as Clark (2007) suggests, we are profoundly embodied agents, ones capable of “incorporating new resources and structures deep into their problem-solving engines” (Clark, 2007, p. 277), then it seems at least possible that the Web may serve as the target of future forms of biotechnological merger, perhaps even extending the machinery of the mind to encompass aspects of the online world (see Smart, 2012).

In addition to this potential transformation of our individual cognitive profiles, the Web also affords new opportunities for social interaction and engagement, made possible by an ever-expanding array of social media sites and social networking applications. We have, as yet, little understanding of how these new technologies will affect the social aspects of human cognition, both in terms of our ability to process social information as well as our ability to distribute cognitive processes across groups of individuals. Again, this seems to constitute an important area of attention for the 4E theorist. Sociocultural factors often surface in 4E discussions of

human cognition (e.g. Hutchins, 2008), and the social aspects of cognition are an increasingly important focus of theoretical and research attention in the embodied mind literature (Smith, 2008).

In this chapter, I attempt to provide an overview of some of the issues that are raised when looking at the Web through the lens of 4E approaches to cognition. I first discuss the way in which emerging forms of interaction with the Web may lay the basis for future forms of Web-based cognitive extension (Smart, 2012). I then go on to discuss some of the issues surrounding what might be called the “Social Web” – the part of the Web that is concerned with the enablement of social interactions, social relationships and collaborative enterprises.

Embodiment and the Real World Web

At first sight, a discussion of the Web may seem somewhat out of place in a text on embodied cognition. Work within embodied cognition (and 4E cognition, in general) tends to focus on situations in which we are actively engaged with the real world, exploiting all manner of sensorimotor cues in order to realize intelligent thought and action. The nature of our interaction with the Web seems far removed from this sort of situation. Even though we might be justified in seeing the Web as an important part of the context in which cognition occurs – part of the material backdrop against which our thoughts and actions take shape – it is by no means clear that the details of our physical embodiment and environmental embedding really matter that much when it comes to understanding the nature of our online interactions.

One response to the claim that Web-based interactions are not a legitimate point of interest for the embodied cognition theorist is to downplay the distinction between the notions of online and offline behavior. Thus it might be argued that our interaction with the Web is, in fact, a genuine case of embodied interaction which surely does take place in the real world. The nature of the sensorimotor dynamic might be different from that seen in the case of (e.g.) running to catch a fly ball (see McBeath, Shaffer, and Kaiser, 1995), but it is far from clear that all the details of material embodiment and environmental embedding are irrelevant to understanding our life online. It might also be said, of course, that an increasing amount of cognition takes place online – that the Web is a forum in which we confront some of our most potent intellectual and cognitive challenges. It would be disappointing, indeed, if the 4E theorist had nothing to say about such matters.

Another response to the challenge that the Web falls outside the realms of interest for the embodied cognition theorist is to deny that the traditional notions of online and offline interaction are of any real relevance when it comes to contemporary forms of interaction and engagement with the Web. Our predominant vision of online interaction is one in which we are sitting in front of a desktop computer, accessing the Web through a conventional browser-based interface (such as Internet Explorer or Google Chrome). In these cases, we are encouraged to see the flow of our thoughts as somewhat decoupled from the “real world,” as occurring in response to remotely located information resources and as being largely unaffected by events in the sensory periphery of the computer screen. The advent of mobile and portable computing solutions is, of course, changing all this. Increasingly, our interactions with the Web are ones that take place in the context of our everyday sensorimotor engagements with the world, where our attention constantly switches from the Web to the wider world according to the demands of the tasks in which we are engaged. Consider, for example, the case of a person equipped with an iPhone and located in an unfamiliar city. Suppose this person’s knowledge of the city in question is limited, but they wish to walk to a nearby location. We now see them engaged in a behavior where the act of walking to the location is guided by the feedback they receive from

their GPS- and Web-enabled device. For the most part, the individual's attention is focused on aspects of the physical environment (cars, people, pushchairs, and various other obstacles). However, at critical junctures in the journey, attention adverts to the iPhone and information is retrieved in order to inform decisions about which direction to take. How should we view the online/offline status of the person in this case? Are they online, offline or some mixture of the two? It is in cases like these, I suggest, where the emerging panoply of portable devices and modes of practice concerning Web usage lead to an effective blurring of our notions about what constitutes online and offline behavior. The new devices enable us to interleave our interactions with the Web and the real world in a way that makes the traditional distinction between offline and online interaction of nugatory significance. As Floridi (2011) suggests, our lives are increasingly complex mergers of online and offline interaction – our lives are increasingly led “onlife.”

The growing trend in the use of mobile and portable computing solutions marks an important shift in the way in which we access the Web, and it is one that opens up a range of opportunities for us to exploit Web-based content as part of our everyday embodied interactions with the world. The trend is likely to continue in the near future with the advent of wearable computing solutions, such as the head-mounted augmented reality display device envisioned by Google's Project Glass initiative. These sorts of devices promise to transform the nature of our contact with the Web, making information directly available within the visual field and thereby reducing the need to switch our attention between a technological resource (e.g. an iPhone) and the real world. In addition, such devices promise to reduce the demand placed on our bodies to manage information retrieval operations. In the case of Google's Project Glass, for example, it has been suggested that the device will be sensitive to natural language voice commands, thereby enabling hands-free modes of operation. These kinds of interaction are important because they liberate bodily resources to engage in other kinds of activities, some of which may be essential to embodied cognitive processes. Crucially, from an embodied cognition perspective, hands-free modes of operation allow the user to engage in gestures, and these have been shown to play a role in enhancing various aspects of human cognitive processing (Goldin-Meadow, 2003; McNeill, 2005).

Another device that is of interest in the current context is the Web-enabled umbrella described by Matsumoto and colleagues (Matsumoto, Hashimoto, and Okude, 2008). The umbrella features a variety of sensors (e.g. GPS, compass, accelerometer, etc.), and it is able to project Web-based content directly into the user's field of view by virtue of a projection device focused on the underside of the umbrella canopy. By providing the user with a range of interaction opportunities (e.g. the normal turning, dipping and twisting actions that people perform with umbrellas), and by also integrating information from a variety of sensors and Web services, the umbrella is able to present a variety of forms of context-relevant information that take into account both the user's physical location as well as their current interests and activities. Interestingly, and of particular relevance in the current context, Matsumoto *et al.* (2008) describe their work as part of an effort to realize what they call the “Embodied Web”: a form of enhanced interactivity in which “natural embodied interactions ... augmen[t] [a user's] experience in the real world” (Matsumoto *et al.*, 2008, p. 49).

The work of researchers like Matsumoto *et al.* (2008), as well as the research and development efforts of organizations like Google, will, in all likelihood, transform the nature of our future interaction with the Web. In place of conventional forms of browser-based access, we are witnessing the transition to an era in which the Web is placed at the heart of our everyday embodied interactions with the world. We may view the end state of this transition as resulting in what has been called the “Real World Web” (Smart, 2012), a vision of the Web in which

we encounter increasingly intimate forms of sensorimotor contact with Web-based information. The realization of this vision will serve to blur the distinction between online and offline behavior and enable us to see the Web as just another part of what Hutchins (2010) calls the “cognitive ecology” – the set of neural, bodily, social, technological and environmental factors that together shape the course of our cognitive endeavors.

The Web-extended mind

Devices that increase both the accessibility and perceptual availability of Web-based information have a number of implications for how we view the potential cognitive impact of the Web. One such implication concerns the possibility for Web-based forms of cognitive extension in which the technological and informational elements of the Web come to form part of the supervenience base for (at least some) mental states and processes. As part of their seminal paper on the extended mind, Clark and Chalmers (1998) outlined a thought experiment in which a neurologically impaired individual, Otto, relied on the use of an external resource (a notebook) in order to achieve certain tasks. The main point of the thought experiment was to highlight the similar functional role played by both biological (i.e. the brain/body) and non-biological (e.g. the notebook) resources in supporting at least some cases of intentional action. Inasmuch as the bio-external resources played a role similar to that served by biological resources, Clark and Chalmers claimed, we should view their contributions to global behavior as on a functional par. This would, at least in some cases, enable us to see bio-external resources as playing a constitutive role in the realization of mental states and processes. When we apply such notions to the Web, we can entertain the possibility of Web-extended minds, or minds in which the technological and informational elements of the Web come to be seen as part of the physical machinery of a biotechnologically hybrid cognitive system (see Smart, 2012).

In order to outline the notion of the Web-extended mind, we can adapt the example provided by Clark and Chalmers, dispensing with the technologically low-grade notebook and replacing it with technologies that support sophisticated forms of Web access (in the manner alluded to by the vision of the Real World Web). Let us therefore imagine a human agent who is equipped with a mobile networked device (a mobile phone will do) in order to provide wireless access to the Web, an augmented reality head-mounted display device (similar to the technological target envisioned by Google’s Project Glass initiative), and a means of controlling information retrieval (for the sake of argument, imagine something along the lines of the electromyographic, electroencephalographic and electrooculographic interfaces currently being developed by a variety of academic and commercial organizations [Mason, Bashashati, Fatourehchi, Navarro, and Birch, 2007; Nicolelis, 2001]). Thus equipped, our subject is able to retrieve information from the Web, on demand, in a manner that is able to shape the course of their thoughts and actions in a number of task contexts. Our subject could, for example, be guided to the location of interesting spatial targets by the use of simple geo-registered directional indicators overlaid onto the visual field. Our subject would not, therefore, have to rely on bio-memory to recall facts, such as the location of particular places of interest, because location-aware services would retrieve and present this information in a way that would serve to guide ongoing behavior. Similarly, imagine that our subject has an interest in baseball and that baseball facts and figures are continually posted on the Web in a form that permits flexible forms of retrieval, combination, aggregation and inference (for example, the data might be available in the form of a linked data resource [see Heath and Bizer, 2011]). In this situation, our subject would be able to retrieve any piece of baseball-related information, on demand, in a manner that is robustly and continuously available. What would our impressions be about the subject’s epistemic

capabilities in this situation? Would it be appropriate for us to say that the subject pretty much “knows” everything there is to know about baseball, at least in terms of the information that is posted on the Web? One reason to suspect that this might be the case is that what seems to determine whether we know or do not know something is not the fact that we are continuously, consciously aware of relevant facts and figures; rather, what seems to count is more the kind of access we have to relevant information. If our access to externally located information was just as reliably, easily and continuously available as the kind of access afforded by our own bio-memories, then we could question whether there is any principled reason to insist that the external information would not count as part of our own personal body of knowledge and (dispositional) beliefs about the world (see Clark, 2003, p. 42).

The social Web

In addition to its potential effects on our individual cognitive profile, the Web also plays an important role in socially situated cognition. Ever since the advent of Web 2.0, which is characterized by greater levels of user participation in the creation, maintenance and editing of online content, the Web has provided ample opportunities to support various forms of socially distributed information processing. In addition, the recent surge in social media sites (e.g. YouTube), social networking systems (e.g. Facebook) and microblogging services (e.g. Twitter) has opened up new ways for people to interact, communicate and share information content. We are increasingly seeing the emergence of what we might call the “Social Web”: a suite of applications, services, technologies, formats, protocols and other resources, all united in their attempt to both foster and support social interaction.

Perhaps unsurprisingly, the Social Web is of considerable interest to those who approach cognition from a 4E perspective. This is because human cognition is often seen as a socio-culturally situated activity, and great emphasis is placed on the role of social forces and factors in shaping our cognitive capabilities. One point of interest here for the 4E theorist concerns the nature of socially derived information on the Web and the way in which this information influences the processes associated with person perception and social sense-making (i.e. the attempt to understand the behavior of others in terms of intentional mental states). Research in this area has revealed that cues derived from the online environment (e.g. information about a person’s social network) can be used to drive social judgments relating to (e.g.) credibility, extraversion, popularity and social attractiveness (Tong, Van Der Heide, B., Langwell, L., and Walther, 2008; Westerman, Spence, and Van Der Heide, 2012). Such findings highlight an issue of critical importance when it comes to the Web’s role in supporting social cognition. This is the fact that many of the cues available in the online realm are ones that could not be (easily) accessed in conventional face-to-face contexts. Thus, rather than see Web-based forms of social interaction as an inherently weaker or impoverished version of that which takes place in conventional face-to-face encounters (at least from the perspective of social cognition), we are encouraged to view the Web as an environment that surpasses many of the constraints associated with co-presence and co-location. By situating social interaction on the Web, we are presented with a range of opportunities to influence social cognition, and many of these opportunities are simply out of reach in face-to-face social exchanges.

Another point of interest for the 4E theorist concerns the way in which some cognitive processes, such as reasoning, remembering and problem-solving, might be seen as distributed across a group or team of individuals (Hutchins, 1991, 1995). Within the context of the Web and Internet science community, the advent of the Social Web has given rise to an increasing interest in the socially distributed nature of human cognition (Chi, 2008, 2009; Kearns, 2012),

and this interest has been accentuated with the recent explosion in social computing (Parameswaran and Whinston, 2007), human computation (Quinn and Bederson, 2011) and collective intelligence (Bonabeau, 2009) systems. Such technologies focus attention on the ways in which the Web may be used to exploit the latent “sociocognitive capital” possessed by large numbers of physically distributed individuals.

Because of the kinds of opportunities it affords for large-scale collaboration, information sharing, and the coordination of collective efforts, the Web emerges as a seemingly natural platform to realize advanced forms of collective intelligence. However, in spite of the apparent potential of the Web to support socially distributed cognition, it is important to understand that not all forms of Web-based social interaction and information exchange necessarily lead to improvements in collective cognitive processing. It is known, for example, that the rate at which information and ideas are distributed through a social network can have a profound effect on group-level cognitive outcomes, and this highlights a source of tension in our attempts to engineer systems that support socially distributed cognition in Web-based contexts. On the one hand, we are usually inclined to countenance high-bandwidth communication systems that feature high levels of connectivity and which maximize the efficient and widespread dissemination of information to all members of a community. On the other hand, we encounter a range of findings in the social psychological and multi-agent simulation literature that suggest that such systems may not always deliver the best outcomes in terms of collective cognitive performance. In some situations, at least, the rapid communication of information and ideas does not always serve the collective cognitive good: precipitant forms of information sharing can sometimes subvert rather than support socially distributed cognition (Hutchins, 1991; Lazer and Friedman, 2007).

What all this means, of course, in terms of our attempt to support socially distributed cognition on the Web, is that we need to develop a better understanding of the effect that different forms of information flow and influence have on collective cognitive outcomes. One factor that has emerged as an important focus of research attention, in this respect, is the structure of the communication network in which individuals are embedded. Research has shown that the structure of the communication network shapes the flow of information between individuals, and this can lead to different effects on group-level performance. Interestingly, the suitability of different forms of network structure seems to depend on the nature of the task that is being performed (Kearns, 2012). Thus, when subjects are confronted with a simple problem it seems that the best structure is one that connects all individuals to every other individual in the group (i.e. a fully connected network) (Lazer and Friedman, 2007; Smart, Huynh, Braines, and Shadbolt, 2010). On more complex problems, however, it seems that more limited forms of connectivity are desirable because such networks essentially impede the rate of information flow between the individuals and thus prevent premature convergence on suboptimal or inaccurate solutions (Lazer and Friedman, 2007; Smart *et al.*, 2010).

Another factor that has proved of considerable research interest concerns the amount of feedback that is given to individuals about the progress or status of collective cognitive processing. This is of particular interest in a Web-based context since the Web provides a unique opportunity to gather and exploit information about the judgments, decisions or activities of individual participants. Consider, for example, the attempt by a group of users to derive an estimate of some unknown parameter. For the sake of argument, let us say that participants are asked to estimate the number of crimes that are recorded in the city of London. In this situation, the statistical average of everyone’s estimates should approximate the actual number of crimes recorded, and this exemplifies one way in which a system like the Web may be used to exploit what has become known as the “wisdom of crowds” (Surowiecki, 2005). Imagine,

however, that a Web-based system that mediates this instance of collective intelligence provides feedback on the estimates that have been made by users on previous occasions. How will the provision of this information influence the ratings of new users? And, in the long term, will the feedback lead to better or worse performance relative to what might be expected in situations where no feedback is given at all?

In order to answer these questions, Lorenz and colleagues (Lorenz, Rauhut, Schweitzer, and Helbing, 2011) devised an experiment in which participants were asked to generate ratings in response to a number of questions – the answers to which were not known in advance by any one individual. They then manipulated the level of feedback that participants were given about the responses of other participants across a number of trials. Their results reveal that feedback often works to undermine collective performance. Rather than being able to derive estimates that were, at the collective level, close to the actual answer, subjects in the high-feedback condition settled on responses that were, at the collective level, worse than those seen in situations where subjects received no feedback at all. In accounting for their results, Lorenz *et al.* (2011) posit a “social influence effect” in which the feedback about other users’ ratings is deemed to progressively reduce the diversity of ratings within the group without a corresponding improvement in group-level accuracy. These results suggest that although the Web provides an environment in which a variety of kinds of information can be gathered during the course of socially distributed information processing, not all of this information *should* be made available to the individual agents engaged in the process. Instead, the results call for a more nuanced approach in which the system works to adaptively regulate the availability of different kinds of information in ways that are sensitive to the nature of the task that is being performed, as well as the psychological propensities of the participating agents. In essence, what is required is a way of dynamically organizing the set-up of Web-based socio-technical systems in order to meliorate group-level cognitive processes in a variety of different task contexts.

Conclusion

A key feature of the embodied cognition perspective is the emphasis it places on extraneural factors in accounting for our human cognitive success. In particular, the embodied cognition perspective emphasizes the fact that the human brain is an extremely plastic, profoundly embodied and socioculturally situated organ. Rather than see intelligence as something that is located in a purely inner, neural realm, embodied cognition emphasizes the way in which cognition depends on forces and factors that are distributed across the brain, the body and the world. This emphasis makes the World Wide Web of considerable interest to the embodied cognition theorist; for the Web is an increasingly prevalent part of the wider cognitive ecology in which some of our most intellectually and cognitively challenging endeavors are situated. A number of emerging technologies seem poised to place the Web at the heart of our everyday sensorimotor interactions with the world, and inasmuch as we are profoundly embodied agents, constantly engaged in the renegotiation of our bodily and cognitive frontiers (see Clark, 2007), the Web seems to provide a range of opportunities for the deep and transformative restructuring of our cognitive capabilities.

The Web is also a platform for social interaction and engagement, and this opens up the possibility that the Web may lead to new forms of socially situated and socially distributed cognition. One point of interest concerns the way in which the Web can support forms of social cognition associated with person perception and social understanding. Recent research is suggesting that by situating social interactions on the Web, we are provided with a range of opportunities to influence social cognition, and these opportunities are often out of reach in

conventional face-to-face contexts. Similarly, when it comes to socially distributed cognition, the Web provides a platform in which we have a relatively unique opportunity to organize information flows in ways that fully exploit the sociocognitive capital of geographically dispersed individuals.

References

- Bonabeau, E. (2009). Decisions 2.0: The power of collective intelligence. *MIT Sloan Management Review*, 50(2), 45–52.
- Chi, E. H. (2008). The social Web: Research and opportunities. *Computer*, 41(9), 88–91.
- (2009). Augmented social cognition: Using social web technology to enhance the ability of groups to remember, think, and reason. *Proceedings of the 35th ACM SIGMOD International Conference on Management of Data*. New York: Association of Computing Machinery.
- Clark, A. (2003). *Natural-born cyborgs: Minds, technologies and the future of human intelligence*. Oxford: Oxford University Press.
- (2007). Re-inventing ourselves: The plasticity of embodiment, sensing, and mind. *Journal of Medicine and Philosophy*, 32(3), 263–82.
- (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. New York: Oxford University Press.
- Clark, A., and Chalmers, D. (1998). The extended mind. *Analysis*, 58(1), 7–19.
- Floridi, L. (2011). The construction of personal identities online. *Minds and Machines*, 21(4), 477–79.
- Goldin-Meadow, S. (2003). *Hearing gesture: How our hands help us think*. Cambridge, MA: Harvard University Press.
- Heath, T., and Bizer, C. (2011). *Linked data: Evolving the web into a global data space*. San Rafael, CA: Morgan & Claypool.
- Hutchins, E. (1991). The social organization of distributed cognition. In L. Resnick, J. Levine, and S. Teasley (eds.), *Perspectives on socially shared cognition*. Washington, DC: American Psychological Association.
- (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.
- (2008). The role of cultural practices in the emergence of modern human intelligence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1499), 2011–19.
- (2010). Cognitive ecology. *Topics in Cognitive Science*, 2(4), 705–15.
- Kearns, M. (2012). Experiments in social computation. *Communications of the ACM*, 55(10), 56–67.
- Lazer, D., and Friedman, A. (2007). The network structure of exploration and exploitation. *Administrative Science Quarterly*, 52(4), 667–94.
- Lorenz, J., Rauhut, H., Schweitzer, F., and Helbing, D. (2011). How social influence can undermine the wisdom of crowd effect. *Proceedings of the National Academy of Sciences of the United States of America*, 108(22), 9020–25.
- Mason, S., Bashashati, A., Fatourechi, M., Navarro, K., and Birch, G. (2007). A comprehensive survey of brain interface technology designs. *Annals of Biomedical Engineering*, 35(2), 137–69.
- Matsumoto, T., Hashimoto, S., and Okude, N. (2008). The embodied Web: Embodied Web-services interaction with an umbrella for augmented city experiences. *Computer Animation and Virtual Worlds*, 19(1), 49–66.
- McBeath, M. K., Shaffer, D. M., and Kaiser, M. K. (1995). How baseball outfielders determine where to run to catch fly balls. *Science*, 268(5210), 569–73.
- McNeill, D. (2005). *Gesture and thought*. Chicago: University of Chicago Press.
- Nicolelis, M. (2001). Actions from thoughts. *Nature*, 409(6818), 403–7.
- Parameswaran, M., and Whinston, A. B. (2007). Research issues in social computing. *Journal of the Association for Information Systems*, 8(6), 336–50.
- Quinn, A. J., and Bederson, B. B. (2011). Human computation: A survey and taxonomy of a growing field. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. New York: Association of Computing Machinery.
- Shapiro, L. A. (2011). *Embodied cognition*. Abingdon, Oxfordshire: Routledge.
- Smart, P. R. (2012). The Web-extended mind. *Metaphilosophy*, 43(4), 426–45.
- Smart, P. R., Huynh, T. D., Braines, D., and Shadbolt, N. R. (2010). Dynamic networks and distributed problem-solving. Paper presented at the conference, Knowledge Systems for Coalition Operations (KSCO'10), Vancouver, British Columbia, Canada. Retrieved from <http://eprints.soton.ac.uk/271508/>

- Smith, E. R. (2008). Social relationships and groups: New insights on embodied and distributed cognition. *Cognitive Systems Research*, 9(1), 24–32.
- Surowiecki, J. (2005). *The wisdom of crowds: Why the many are smarter than the few*. New York: Random House.
- Tong, S. T., Van Der Heide, B., Langwell, L., and Walther, J. B. (2008). Too much of a good thing? The relationship between number of friends and interpersonal impressions on Facebook. *Journal of Computer-Mediated Communication*, 13(3), 531–49.
- Westerman, D., Spence, P. R., and Van Der Heide, B. (2012). A social network as information: The effect of system generated reports of connectedness on credibility on Twitter. *Computers in Human Behavior*, 28: 199–206.

THE CONSTITUTION OF GROUP COGNITION

Gerry Stahl

Cognition at multiple levels

There is a venerable tradition in philosophy that cognition is a mysterious faculty of individual human beings. Increasingly since the late nineteenth century, it has become clear that even when thoughts appear to be expressed by an individual they are the product of more complex factors. Cognitive abilities and perspectives develop over time through one's embeddedness in a physical, social, cultural and historical world. Thinking is closely related to speaking, a form of communication with others. Particularly in our technological world, thinking is mediated by a broad variety of artifacts and by other features of the context in which we are situated.

Rather than thinking about thinking, I try to explore cognition by generating data in which one can observe cognitive processes at work (Stahl, 2006, 2009, 2013). I do this by having small groups of students collaborate on mathematical problems in a setting where their whole interaction can be captured. The motivation for this approach is the theory of Vygotsky, the sociocultural psychologist who proposed that higher-level human mental abilities are acquired first in small-group interactions. In exploring such group cognition, I have found that there is a rich interplay of processes at individual, small-group and community levels of cognitive processing.

In the following, I will summarize three case studies in order to illustrate how cognitive processes at multiple levels can work together. In the first case, two students solve a high-school math problem that has stumped them for some time. The problem-solving steps the dyad go through as a team are typical for how proficient students solve problems individually. In the discourse captured in this case, one can see how the *group* integrates contributions from the two *individual* participants to accomplish a task in accordance with *community* standards of practice—illustrating the productive interplay of cognitive levels. The sequence of ten discourse moves by the group details their extended *sequential approach* to the problem. In the second study, three students develop techniques for helping each other to see what they are seeing in the diagram they have drawn for a math problem. This *persistent co-attention* to a shared object of analysis allows the team to solve their problem as a group. Similarly in the third example, the students are able to work together because they effectively manage their *shared understanding* of the problem.

I propose that it is often fruitful to analyze cognition on multiple levels and that the processes at the different levels work together. A variety of *interactional resources* are typically at work

bridging the levels. In the three illustrative case studies, topics in high-school mathematics centrally figure as resources that bring together individual, small-group and community cognitive processes.

Virtual math teams

The study of group cognition requires careful review and analysis of all the interaction within a group during the achievement of a cognitively significant task, such as solving a challenging problem. I have arranged for this by designing an online software environment in which several people can meet and interact effectively to solve math problems. This Virtual Math Teams (VMT) environment supports synchronous text chat and a shared whiteboard for drawing figures (Stahl, 2009). Recently, it has been expanded to incorporate a multi-user version of dynamic geometry, in which geometric figures can be interactively constructed and dynamically dragged (Stahl, 2013). The software is instrumented to capture all interaction and to allow it to be displayed, replayed and analyzed. This avoids the many problems of audio and video recording in classrooms. Students communicate online, avoiding the interpretational issues of eye gaze, bodily gesture and vocal intonation. When possible, groups are composed of students who do not know each other outside of the online setting, so that researchers reviewing a record of interaction can know everything about the participants and their background knowledge that the participants know about each other. Since group cognition is defined as consisting of those knowledge-building or problem-solving processes that take place in the group interaction (Stahl, 2006), the VMT environment can capture a complete history of group-cognitive events.

When a group enters the VMT environment, it is presented with a challenging math problem, designed to guide the group interaction in an academically productive direction. The problem acts as a resource for the group. The group must interpret the problem statement, elaborate the way in which it wants to conceive the problem and determine how to proceed. A math problem can serve as an effective interactional resource for bridging across cognitive levels. Typically, it introduces content—definitions, elements, procedures, principles, practices, proposals, theorems, questions—from the cultural traditions of mathematics and from school curriculum. In so doing, it recalls or stimulates individual cognitive responses—memories, skills, knowledge, calculations, deductions. It is then up to the group interaction to bring these together, to organize the individual contributions as they unfold in the ongoing interaction in order to achieve the goals called for by the community, institutional, disciplinary and historical sources. In this way, the group interaction may play a central role in the multilevel cognition, interpreting, enacting and integrating elements from the other levels, producing a unified cognitive result and thereby providing a model for future community practice or individual skill.

It may seem ironic that an online environment has been selected for the empirical study of how cognition is “embodied” in group interactions and community contexts. In the VMT environment, participants are not physically present to each other. They do not see interactional contributions being produced by individuals. Rather, text chat postings suddenly appear as complete units on the screen and geometric elements are drawn or dragged without visible hands manipulating them. As we will see below, Aznx does not see how Bwang is gradually putting together and occasionally repairing a sentence to be posted. Jason cannot follow Qwertyuiop’s gaze to see where his attention is focused. Yet, there are some elements of embodiment, at least virtually. Each participant is represented in the VMT interface with a login handle associated with their chat postings. There are awareness notices indicating who is typing a pending chat contribution or who is engaged in a geometric construction action. The software interface presents a complexly structured visual manifold. Students quickly develop

online practices to adapt to the new environment, to overcome the limitations of the media and to implement alternative means for missing abilities, as seen in the following case studies. Within this computer-mediated context, individual and group levels of cognition are focused on situated entities from specific perspectives; multilevel cognition is embodied in an inter-subjective world.

Constructing diamonds

Cognition is neither a unitary phenomenon nor a temporally fixed one. Hegel described the logical stages involved in the development of cognition in his *Phenomenology of Mind* (1807/1967). Vygotsky explored the development of a person's cognition through psychological experiments reported in *Mind in Society* (1930/1978), emphasizing the priority of intersubjective group cognition:

Every function in the child's cultural development appears twice: first, on the social level, and later, on the individual level; first, between people (*interpsychological*), and then *inside* the child (*intrapsychological*). This applies equally to voluntary attention, to logical memory, and to the formation of concepts. All the higher [human mental] functions originate as actual relations between human individuals.

(p. 57)

Research on CSCL (computer-supported collaborative learning) (Stahl, Koschmann, and Suthers, 2013) can make visible the development and the unfolding of cognitive functions in small groups, shedding light on the less-visible processes that can subsequently be carried out by people individually or “internally.” A research method for undertaking such analysis is suggested by the field of conversation analysis (CA) (Sacks, 1962/1995). CA was inspired by ethnomethodology, a sociological approach focused on describing the “work” that people typically do in interactions with others to establish social order and to construct meaning (Garfinkel, 1967). CA applies this approach to analyzing everyday conversation. A central finding of CA is that the work of conversation is accomplished through the sequential construction of “adjacency pairs,” short sequences in which one person's utterance elicits a response in the form of a following utterance by an interlocutor—for instance a question-answer pair. In looking for examples of mathematical problem solving by groups, we are more interested in “longer sequences,” in which a series of adjacency pairs are constructed to accomplish the larger cognitive goal.

Longer sequences have only been suggested in CA (Sacks, 1962/1995, Vol. 2, p. 354; Schegloff, 2007, pp. 12, 213), not extensively analyzed. In the final excerpt from a VMT interaction among three students, I analyzed their successful problem-solving effort as a longer sequence, consisting of ten discourse moves, each linguistically organized as an adjacency pair (Stahl, 2011). I treated their four-hour-long online interaction in terms of a temporal hierarchy of: a group event, four scheduled sessions, several conversational topics, many discourse moves, adjacency pairs, textual utterances and indexical references. In the first session, the students had been asked to work on a topic in mathematical combinatorics, determining the number of squares and composite sticks needed to build a stair-step pattern at different stages of growth. By the fourth session, the students had set themselves the topic of analyzing a diamond pattern, illustrated by them at stages $n = 2$ and $n = 3$ in the screen image of the VMT software interface in Figure 32.1.

In their final conversational topic, two students with login names of Bwang and Aznx decide to try again to solve this problem, despite not being able to do so for the past two hours and

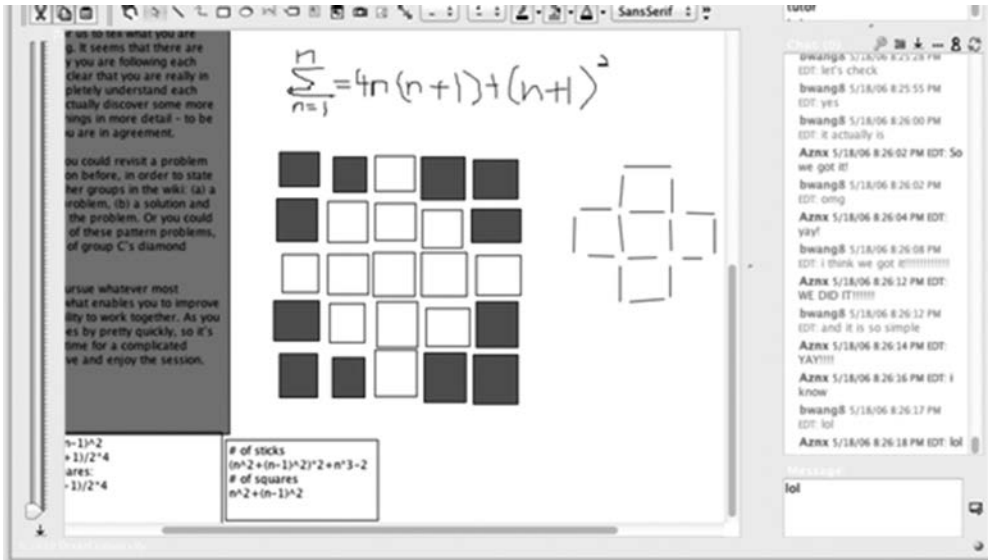


Figure 32.1 Discussion and drawings of diamond pattern.

despite the fact that their scheduled online time is already over. In the course of ten minutes, 100 chat lines of text are posted. The analysis highlights ten adjacency pairs that were central to this discourse. Each adjacency pair is listed in Log 1, under an added descriptive heading. Although there is not space here to provide the full chat or a complete analysis, this selection from the interaction should give a sense of the problem-solving process.

Log 1. Ten moves of the problem-solving topic.

Move 1. Open the topic

Bwangs: i think we are very close to solving the problem here

Azrx: We can solve on that topic.

Move 2. Decide to start

Bwangs: well do you want to solve the problem

Azrx: Alright.

Move 3. Pick an approach

Azrx: How do you want to approach it?

Bwangs: 1st level have 1×4 ... 4th level have $(1+3+5+7) \times 4$

Move 4. Identify the pattern

Azrx: So it's a pattern of $+2s$?

Bwangs: yes

Move 5. Seek the equation

Bwangs: what is it

Azrx: n^2 ... or $(n/2)^2$

Move 6. Negotiate the solution

Aznx: its n^2

Bwang: so that's wrong

Move 7. Check cases

Aznx: would be $4n^2$

Bwang: it actually is

Move 8. Celebrate the solution

Bwang: i think we got it!!!!!!!!!!!!

Aznx: WE DID IT!!!!!!

Move 9. Present a formal solution

Aznx: So you're putting it in the wiki, right?

Bwang: yes

Move 10. Close

Aznx: we should keep in touch

Bwang: yeah

There are several things to note here:

- Most importantly, the sequence of moves is strikingly similar to how an experienced math problem solver might approach the topic individually, as described at a particular granularity.
- The two students take turns contributing to the shared topic. The group direction is not set by either individual, but results from their interaction.
- Most opening utterances solicit a response, often in the explicit form of a question, and they always await a response.
- Each move is a situated response to the current state of the students' understanding of the topic as expressed in the discourse—rather than some kind of logical progression following a plan based on some kind of goal-subgoal hierarchy (Suchman, 2007).
- The focus of the group discourse moves is on the sharing, negotiation and agreement about their progress, rather than on details of mathematical facts or computations.
- The math content is handled by the individuals and contributed by them into the collaborative setting, for instance in move 3 or 5.
- The temporal structure of topics, moves and adjacency pairs is not imposed by the analyst, but is projected in the remarks of the participants as integral to how they make meaning for themselves about what they are doing.

If one follows the development of the students' understanding in their postings across the four sessions, one is struck by changing roles and confidence levels, as well as by their mastery of practices that one or the other introduced into the group. It is quite plausible that over time the lessons acquired in their collaborative interactions become manifested in their individual cognitive skills. The longer sequences of argumentation or problem solving become "internalized" (as Vygotsky called it) or adopted as cognitive practices of individuals. The power of collaborative learning is partially to bring together multiple perspectives, which can be debated, negotiated, synthesized, contextualized, structured and refined. However, another advantage is to extend the cognitive effort into *longer sequences* of argumentation through the stimulation and enjoyment of productive social interaction, increasing the time-on-task as needed to solve challenging

problems. Thus, groups can achieve cognitive accomplishments that their members cannot—and the members can learn from these achievements.

Visualizing hexagons

Elsewhere, we have analyzed in some detail the intimate coordination of visual, narrative and symbolic activity involving the text-chat and shared whiteboard in VMT sessions (Çakir and Stahl, 2013; Çakir, Zemel, and Stahl, 2009). Here, we want to bring out the importance of literally looking at some mathematical object together in order to share the visual experience and to relate to—to intend or to “be at”—the entity together. People often use the expression “I do not see what you mean” in the metaphorical sense of not understanding what someone else is saying. In our second case study, we often encounter the expression used literally for not being able to visually perceive a graphical object, at least not being able to see it in the way that the speaker apparently sees it.

While empiricist philosophy refers to people taking in uninterpreted sense data much like arrays of computer pixels, post-cognitive philosophy emphasizes the phenomenon of “seeing as.” Wittgenstein noted that one immediately sees a wire-frame drawing of a cube not as a set of lines, but as a cube oriented either one way or another (1953, §177). For Heidegger, seeing things as already meaningful is not the result of cognitive interpretation, but the precondition of being able to explicate that meaning further in understanding (1927/1996, pp. 139f.). For collaborative problem solving and mathematical deduction, it is clearly important that the participants see the visual mathematical objects as the same, in the same way. This seems to be an issue repeatedly in the online session excerpted in Log 2, involving three high-school students with login handles of Jason, Qwertyuiop and 137 (Stahl, Zhou, Cakir, and Sarmiento-Klapper, 2011).

Student 137 proposes a mathematical task for the group in line 705 of Log 2. This is the first time that the term, “hexagonal array,” has been used. Coined in this posting, the term will become sedimented (Husserl, 1936/1989, p. 164) as a mathematical object for the group as the discourse continues. However, at this point it is problematic for both Qwertyuiop and Jason. In line 706, Qwertyuiop poses a question for clarification and receives an affirmative, but minimal, response. Jason, unsatisfied with the response, escalates the clarification request by asking for help in seeing the diagram in the whiteboard *as* a “hexagonal array,” so he can see it *as* 137 sees it. Between Jason’s request in line 709 and acceptance in line 710, Qwertyuiop and 137 work together to add lines outlining a large hexagon in the triangular array. Demonstrating his

Log 2 Seeing a hexagonal array collaboratively.

705	19:15:08	137	So do you want to first calculate the number of triangles in a hexagonal array?
706	19:15:45	qwertyuiop	What's the shape of the array? a hexagon?
707	19:16:02	137	Ya.
708	19:16:15	qwertyuiop	ok...
709	19:16:41	Jason	wait– can someone highlight the hexagonal array on the diagram? i don't really see what you mean...
710	19:17:30	Jason	hmm.. okay
711	19:17:43	qwertyuiop	oops
712	19:17:44	Jason	so it has at least 6 triangles?
713	19:17:58	Jason	in this, for instance

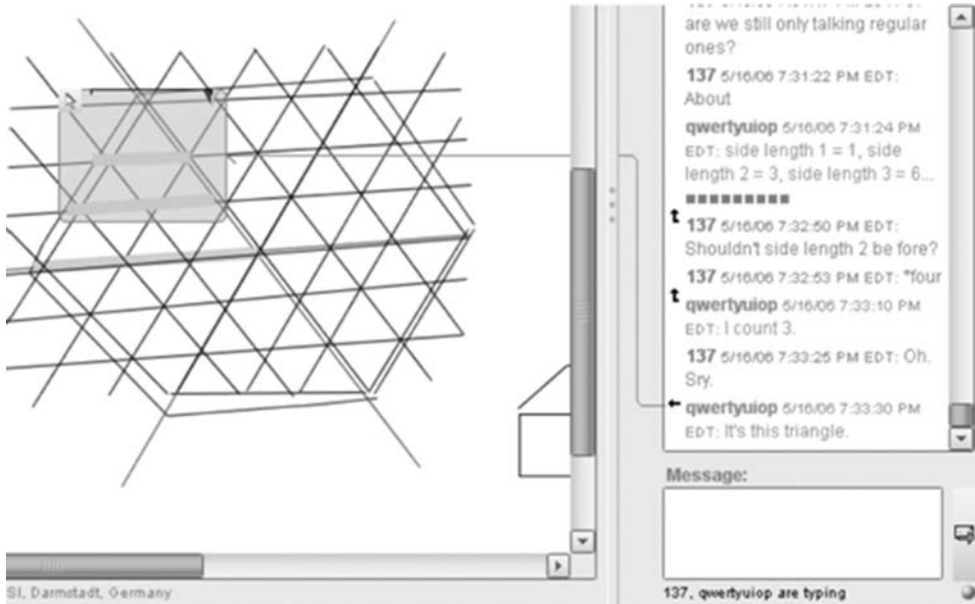


Figure 32.2 Discussion and drawing of hexagon grid.

ability to now see the hexagons, Jason thereupon proceeds with the mathematical work, which he had halted in the beginning of line 709 in order to keep the group aligned. Jason tentatively proposes that every hexagon “has at least 6 triangles” and he makes this visible to everyone by pointing to an illustrative small hexagon from the chat posting, using the VMT graphical pointing tool. Later, the students take turns using these group-defined methods of supporting shared vision and attention: using colored lines and the pointing tool, as seen in Figure 32.2.

Jason dramatically halted group work with his “wait.” For him, it was impossible to continue until everyone could see the same thing in the way that 137 saw it. During this session, the students taught each other how to change the color and thickness of lines they constructed in the shared whiteboard. These were affordances of the VMT software, but the students had to learn how to use the features and they developed certain shared group practices of using colored lines to outline, highlight and draw attention to specific elements of the hexagonal grid. For instance, in Figure 32.2, blue lines outline a hexagon of side length 3; red lines divide that hexagon into six symmetric triangles; thick green lines pick out the three horizontal lines of length 1, 2 and 3 in one of the triangles; and the VMT pointing tool focuses attention on that triangle. There are many ways to count the number of unit sticks in the large hexagon. In order to count them as a group, everyone’s attention must be focused on the same elements, such as the green horizontals. Then it is possible for each participant to count that subset visually: $1 + 2 + 3 = 6$. Through similar shared attention to structural elements of the hexagon, all the group members know that there are three such arrays of lines like the green ones at different orientations in each of the six triangles. They can also see how this array of lines will increase as the hexagon itself progresses to successively longer side lengths. The achievement of the necessary *persistent co-attention* to construct and to follow this complicated analysis was the result of subtle interactions and the development of shared practices within the group.

Inscribing triangles

Our final case involves a group of three middle-school students given a topic in dynamic geometry (Stahl, 2013, §7.3). The students have not yet had a course in geometry, but have already spent four hours together in a version of VMT that incorporates interactive, multi-user support for dynamic geometry. In this topic, the students are given constructions of an equilateral triangle inscribed inside another equilateral triangle and a square inscribed inside another square (see Figure 32.3). In dynamic geometry, a student can drag one point of a figure like the inscribed squares and all the other points and lines will move accordingly, maintaining the geometric relationships or dependencies that have been built into the construction of the figure. In previous sessions, the students had learned the dynamic-geometry equivalent of Euclid's first two propositions: the construction of an equilateral triangle (using software tools equivalent to a straight edge and compass) and the copying of a line-segment length.

In their fifth session, the three students took turns dragging points of the equilateral triangles and discussing the dependencies that were maintained. Then they tried to duplicate the given figure and to build in the relevant dependencies. For instance, the dependency defining the equilateral character of the outer triangle is that the lengths of the second and third sides must always be the same as the length of the base, even when the end points of the base segment are dragged, changing its length. Euclid's construction maintains this dependency because the lengths of all three sides are radii of circles of equal radius. Read today, Euclid's *Elements* (300 BCE/2002) in effect provides instructions for dynamic-geometry constructions. The "elements" of geometry are not so much the points, lines, circles, triangles and quadrilaterals, but the basic operations of constructing figures with important relationships, such as congruence or symmetry. Just as Euclidean geometry contributed significantly to the development of logical, deductive, apodictic cognition in Western thought and in the formative minds of many prospective mathematicians, so collaborative experiences with dynamic geometry may foster in students ways of thinking about dependencies in the world.

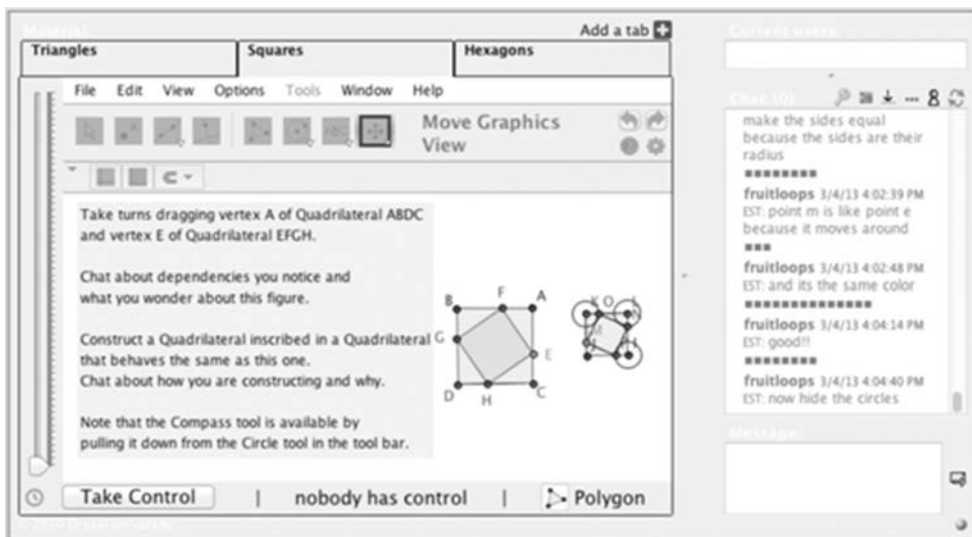


Figure 32.3 Discussion and constructions of inscribed squares.

The students in the case study used Euclid's method to construct the outside triangle, but soon realized that the same procedure could not be used to construct the inscribed triangle, because of the additional constraint that its vertices all had to be on the sides of the inscribing triangle, which they had constructed. Considerable further dragging of points in the given figure and experimentation with various construction approaches were tried. Finally, the students noticed that when one point of the inner triangle was dragged along a side of the outer triangle, the other vertices of the inner triangle moved in a corresponding way, such that their positions along their sides of the outer triangle were the same as that of the dragged vertex on its side. Then they quickly decided to use the method they had learned for copying a line-segment length. They copied the length from one outer vertex of their new equilateral triangle to a point for an inner vertex. Then they placed this length along the other sides, starting at both of the other vertices. This determined the locations of the other inner vertices. When they connected the three points, they formed an inscribed triangle. When any point or line was dragged, both the inner and outer triangles remained equilateral and inscribed.

In their sixth session, the students tackled the topic of inscribed squares. All their previous work in dynamic geometry had involved triangles and they had not been exposed to a method of constructing a dynamic square. They spent most of the hour exploring possible construction methods, eventually inventing a method that was elegantly similar to that of the triangle construction. All three students then immediately saw how to construct the interior square by copying the length from a corner of the exterior square to a corner of the interior one along a side. In Figure 32.3, the circles used for copying the length are still visible. The clarity with which each of the students understood how to inscribe a square—once they were able to construct the exterior dynamic square—shows how well they had each individually mastered the technique from their prior collaborative experience involving the dynamic triangles.

Their collaborative solution of the inscribed-triangles topic is quite typical. We have observed a number of small groups working on this topic, including math teachers, researchers, graduate students and middle-school students. They all go through a similar process of dragging the original figure, experimenting with construction attempts, discovering the dependency of the distances between the interior and exterior vertices, then realizing how to copy that distance and finally checking that their construction has the same behavior as the given figure. While this topic poses a problem that is difficult for individuals, small groups tend to stick with it and solve it through collaborative effort within an hour or less. It takes a combination of many trials, observations and connections to accomplish the task. The collaborative approach allows individuals to contribute specific pieces of the puzzle, to build on each other's proposals and to discuss the implications.

The chat discourse is striking in how much the students make sure that everyone agrees with and understands each step that the group as a whole takes in constructing their figures. In addition to expressing agreement and affirming understanding, the students also demonstrate their *shared understanding* by fluidly building on each other's contributions. Successive steps are generally taken by different students, indicating that they are all following the logic of the collaborative effort.

Contributing to group cognition

The cognition in group cognition is not the same as individual cognition; it relies upon individual cognition to make essential contributions. However, one cannot say that all of the cognition should be analyzed at the individual unit, because the work of assembling the high-level argumentative structure occurs at the group unit of analysis. Surely, putting together problem-solving

arguments must be considered a cognitive activity as much as the work that goes into making the detailed contributions to individual steps. In addition, the personal contributions are largely responses to what has gone before in the group interaction. Not only are these contributions expressions that would not have occurred without the preceding opening up for them and elicitation of them by the group process, but many of the contributions are largely reactions at the group level, which reference and interrelate resources available in the discourse context more than they introduce new elements from the personal perspective and individual background of the actor. The important cognitive achievement is emergent at the group level, rather than a simple collection of expressions of individual cognitive accomplishments.

Coherent and impressive examples of group cognition—such as solving a math problem that the group members would not have been able to solve on their own—do not occur whenever a number of people come together in conversation. In fact, the research field of computer-supported collaborative learning has documented that desirable forms of collaborative knowledge building are hard to find. The three studies summarized above indicate some reasons for this. First, it is difficult to set up a group interaction where everything relevant to the cognition at the group level of analysis is captured in a form adequate for detailed analysis. It took years of research to develop and deploy the VMT environment to successfully generate adequate data for the analysis of group cognition. Second, the group interaction must be directed and guided to focus on an appropriate cognitive task. Certain challenging math problems, carefully presented, seem to provide effective resources for stimulating interesting episodes of group cognition. Additionally—as the three studies summarized here have documented—the groups must work consistently to ensure the presence of certain preconditions of effective group cognition. They must persist in building *longer sequences* of responses to each other, they must maintain continuous *co-attention* to a shared focus of discussion and they must build and sustain a *shared understanding* of the topic of conversation.

The constitution of group cognition

The phenomenological tradition has always conceived of cognition as embodied in the world, rather than as a Cartesian mental process. Husserl (1929/1960, §14) emphasized that cognition is cognition *of* something; it is located at its object, not at some internal representation of that external object. Heidegger (1927/1996) therefore started from the experience of being-in-the-world instead of thinking-in-the-head. For him, cognition is a matter of being-with and caring-for things and people. The world is a shared world and the things we are there with are always already understood as meaningful. In Merleau-Ponty's (1945/2002) famous example of the blind man with the cane, the cane does not so much augment or extend the man's senses and awareness of external reality as it locates his cognition in the world at the tip of the cane.

If we look at the presented examples of group cognition, we see that the students are “there” in their group interaction with mathematical objects, seen in specific ways. Aznx and Bwang have drawn the horizontal sticks and the vertical sticks separately (not shown in the summary above). They have noticed a four-way symmetry, which allows them to reduce the problem of counting the sticks to a tractable pattern. They are focused together on the diamond as that symmetric pattern of sticks. Similarly, Jason, Qwertyuiop and 137 have worked hard to view their hexagonal array as a symmetrical pattern of sticks forming lines within triangles that make up a hexagon. As these groups work out their algebraic solutions to the topic, they are present together in a shared world at an object of interest, which they all see as structured in the same way. In the third case, after much work individually and collaboratively, and incorporating ideas from the ancient tradition of Euclidean geometry, the three students working on the inscribed

squares all observe that when square EFGH is dragged within square ABCD the following segments along the outer square change but stay equal in length to each other: AE, CH, DG, BF. They then can all see that they have to construct square MONP within square IJKL so that segments, IP, JM, KO, LN, stay the same (see Figure 32.3). They collaborate in a shared world, manipulating a shared object physically, visually and imaginatively within a shared understanding of their problem, the geometric objects, the dynamic dependencies, the representational figure and the software affordances.

Following the phenomenologists, the ethnomethodologists showed that the shared social world is constituted continuously through group interaction (Garfinkel, 1967). In our VMT data, we can study precisely how that is accomplished. We see that it takes place over longer sequences of discourse moves, each centered on elicitation/response adjacency pairs. Carrying out these longer sequences requires maintaining persistent co-attention to a shared object; the being-there-together at the object provides a shared focus for the discourse. Accompanying this, there must be a shared understanding of the object and of the discourse context so that group members understand each other. If someone does not know what someone else means by a “hexagonal array” or by its “side length,” does not see the same elements of a symmetrical pattern or the same set of line segments moving together, then the collaborative problem solving cannot continue productively.

Kant (1787/1999) argued that the human mind constitutes meaningful reality through a process of creative discovery, in which structure is imposed to create and discover objects in the world. In the preceding examples, we see how group interaction can constitute the character of objects in the shared world and we have suggested that the shared meaningful world is itself constituted through such interaction. The nature of reality—such as the symmetries of diamond patterns, hexagonal arrays and inscribed squares—is discovered through the creation of interpretive views of objects. Effective perspectives are constrained by reality, which is not knowable except through these views. The creation of perspectives at the level of group cognition shifts the constitutive role from Kant’s individual cognition to group and social cognition. Like the students in the virtual math teams, we first learn to see things *as* others see them in group-cognitive processes (which generally incorporate culturally sanctioned approaches). Subsequently—due to the power of language (e.g. naming, verbal description)—we can be there with those objects (diamonds, hexagons, squares) when we are not physically (or virtually) present with them in a shared group setting. We can even “internalize” (to use Vygotsky’s metaphor) our ability to be-there-with these meaningful objects in the internal speech of individual thought. However, the fact that introspection of adults discovers (and assumes) the existence of many individual mental objects does not mean that those objects were not at some point in our development internalized from group-cognitive experiences in community contexts. An adequate analysis of cognition should recognize the constitutive roles of group cognition and their integration with phenomena of individual and social cognition.

References

- Çakir, M. P., and Stahl, G. (2013). The integration of mathematics discourse, graphical reasoning and symbolic expression by a virtual math team. In D. Martinovic, V. Freiman, and Z. Karadag (Eds.), *Visual mathematics and cyberlearning*. New York: Springer. Retrieved from <http://GerryStahl.net/pub/visualmath.pdf>
- Çakir, M. P., Zemel, A., and Stahl, G. (2009). The joint organization of interaction within a multimodal CSCL medium. *International Journal of Computer-Supported Collaborative Learning*, 4(2), 115–49. Retrieved from http://GerryStahl.net/pub/ijCSCL_4_2_1.pdf
- Euclid. (300 BCE/2002). *Euclid’s elements* (T. L. Heath, Trans.). Santa Fe, NM: Green Lion Press.

- Garfinkel, H. (1967). *Studies in ethnomethodology*. Englewood Cliffs, NJ: Prentice-Hall.
- Hegel, G. W. F. (1807/1967). *Phenomenology of spirit* (J. B. Baillie, Trans.). New York: Harper & Row.
- Heidegger, M. (1927/1996). *Being and time: A translation of Sein und Zeit* (J. Stambaugh, Trans.). Albany, NY: SUNY Press.
- Husserl, E. (1929/1960). *Cartesian meditations: An introduction to phenomenology* (D. Cairns, Trans.). The Hague, Netherlands: Martinus Nijhoff.
- (1936/1989). The origin of geometry (D. Carr, Trans.). In J. Derrida (Ed.), *Edmund Husserl's origin of geometry: An introduction* (pp. 157–80). Lincoln, NE: University of Nebraska Press.
- Kant, I. (1787/1999). *Critique of pure reason*. Cambridge: Cambridge University Press.
- Merleau-Ponty, M. (1945/2002). *The phenomenology of perception* (C. Smith, Trans., 2 ed.). New York: Routledge.
- Sacks, H. (1962/1995). *Lectures on conversation*. Oxford: Blackwell.
- Schegloff, E. A. (2007). *Sequence organization in interaction: A primer in conversation analysis*. Cambridge: Cambridge University Press.
- Stahl, G. (2006). *Group cognition: Computer support for building collaborative knowledge*. Cambridge, MA: MIT Press. Retrieved from <http://GerryStahl.net/elibrary/gc>
- (2009). *Studying virtual math teams*. New York: Springer. Retrieved from <http://GerryStahl.net/elibrary/svmt>
- (2011). How a virtual math team structured its problem solving. In M. Spada, G. Stahl, N. Miyake, and N. Law (Eds.), *Connecting Computer-Supported Collaborative Learning to Policy and Practice: CSCL 2011 Conference Proceedings* (Vol. 1, pp. 256–63). Lulu: International Society of the Learning Sciences (ISLS). Retrieved from <http://GerryStahl.net/pub/cscl2011stahl.pdf>
- (2013). *Translating Euclid: Creating a human-centered mathematics*. San Rafael, CA: Morgan & Claypool. Retrieved from <http://GerryStahl.net/elibrary/euclid>
- Stahl, G., Koschmann, T., and Suthers, D. (2013). Computer-supported collaborative learning: An historical perspective. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (Rev. ed.). Cambridge: Cambridge University Press. Retrieved from <http://GerryStahl.net/pub/chls2.pdf>
- Stahl, G., Zhou, N., Cakir, M. P., and Sarmiento-Klapper, J. W. (2011). Seeing what we mean: Co-experiencing a shared virtual world. In M. Spada, G. Stahl, N. Miyake, and N. Law (Eds.), *Connecting Computer-Supported Collaborative Learning to Policy and Practice: CSCL 2011 Conference Proceedings* (Vol. 1, pp. 534–41). Lulu: International Society of the Learning Sciences (ISLS). Retrieved from <http://GerryStahl.net/pub/cscl2011.pdf>
- Suchman, L. A. (2007). *Human-machine reconfigurations: Plans and situated actions* (2nd ed.). Cambridge: Cambridge University Press.
- Vygotsky, L. (1930/1978). *Mind in society*. Cambridge, MA: Harvard University Press.
- Wittgenstein, L. (1953). *Philosophical investigations*. New York: Macmillan.

33

VARIETIES OF GROUP COGNITION

Georg Theiner

Introduction

Benjamin Franklin famously wrote that “the good [that] men do separately is small compared with what they may do collectively” (Isaacson, 2004). The ability to join with others in groups to accomplish goals collectively that would hopelessly overwhelm the time, energy, and resources of individuals is indeed one of the greatest assets of our species. In the history of humankind, groups have been among the greatest workers, builders, producers, protectors, entertainers, explorers, discoverers, planners, problem solvers, and decision makers. During the late nineteenth and early twentieth century, many social scientists employed the notorious “group mind” idiom to express the sensible idea that groups can function as the seats of cognition, intelligence, and agency in their own right (Allport, 1968; Wilson, 2004). In their quest to stress (rightly) that group phenomena are something “over and above” the sum of individual contributions, a fondness for vitalist metaphors led them to believe (wrongly) that genuine group cognition must be the result of tapping into individualistically inaccessible, “holistic” forces. Today, inspired in part by historically unparalleled forms of mass collaboration enabled by the Internet, it has once again become popular to speak of collective intelligence, group agency, or even the emergence of a “global brain” (cf. the wiki-edited *MIT Handbook of Collective Intelligence* [MIT Center for Collective Intelligence, n.d.]).

In this chapter, I review some contemporary developments of the idea of group cognition, defined broadly as the collaborative performance of cognitive tasks such as remembering, problem solving, decision making, or verbal creativity for the purpose of producing a group-level outcome. My discussion serves a twofold purpose. First, by discussing how the idea of group cognition can be operationalized, I seek to show that we can retain some central theoretical insights of the “group mind” thesis without succumbing to its eccentric metaphysical overtones. Second, by providing a useful array of generalizable taxonomic resources, I hope to foster greater degrees of mutual awareness among insufficiently integrated areas of research on group performance.

From individual to group cognition

When people join together to solve a problem in groups, their performance depends on the knowledge, abilities, and resources of individual members, plus the interpersonal processes that

determine how those are combined into a collective group activity or output. In his seminal work on group productivity, Steiner (1966, 1972) distinguished various types of combination processes in terms of the demands that are dictated by the task a group is trying to solve. He suggested that task demands vary depending on three main dimensions: the divisibility of a task, the desired type of output, and the combination scheme that is used to complete the task. Building on Steiner's taxonomy will help us to tighten our grip on the notoriously slippery notion of group cognition.

Steiner's first dimension concerns the question of whether a task can be broken down into different components. *Divisible* tasks have subcomponents that can be readily identified and assigned to different group members (e.g. running a football play), whereas *unitary* tasks cannot be performed in such piecemeal fashion (e.g. catching a football). The second dimension concerns a distinction between *maximization* tasks that call for a high rate of production, as opposed to *optimization* tasks in which the quality of a performance is measured by comparing it to some predetermined criterion. Running a 400-meter relay is an example of the former, whereas estimating the number of beans in a jar is an example of the latter. Laughlin (1980) similarly proposed a group task continuum that is flanked by *intellective* and *judgmental* tasks. Intellective tasks such as logic or math problems have demonstrably correct solutions within some agreed upon conceptual framework, hence the proposed solutions can be objectively appraised as right or wrong. In contrast, judgmental tasks such as a jury deciding on a verdict, or a hiring committee deciding on a job candidate, involve evaluative judgments for which no single correct answer can be authoritatively determined.

Finally, group tasks can be distinguished in terms of how individual inputs are combined to yield a collective outcome. *Additive* tasks can be solved by summing up the contributions of co-acting individuals. An example would be a university admissions committee whose members independently process student applications without interacting with one another. In *compensatory* tasks, the group outcome is obtained by averaging the independently obtained judgments, estimates, or recommendations of its members. The surprising accuracy of compensatory decision making, which can be explained in terms of general information-theoretic properties of statistical sampling (Bettencourt, 2009), has been popularized lately as the "wisdom of crowds" (Surowiecki, 2004). Surowiecki's opening anecdote tells the story of legendary nineteenth-century polymath Francis Galton, well-known for his elitist obsession with individual genius, who was flabbergasted when he discovered that the crowd at an English country fair had produced a more accurate estimate of an oxen's weight, when their guesses were averaged, than any of the recognized cattle experts. According to Surowiecki, the key to extracting wisdom from crowds is to foster a diversity of opinions, by allowing mutually independent individuals to draw on local, specialized sources of information, and to install a suitable mechanism for aggregating individual judgments (e.g. market pricing, as used in prediction markets). Importantly, the wisdom of crowds is not due to increased levels of collaboration, but results from a relative immunity to performance losses due to imitation, conformism, loafing, and other social phenomena that commonly occur in interacting, especially face-to-face groups.

In contrast, *conjunctive*, *disjunctive*, *discretionary*, and *complementary* tasks all depend more or less directly on interactions among group members. In *cooperative* interactions, all group members share the same goal or objective, and are equally affected by the consequences of a given outcome. This contrasts with *mixed-motive* interactions, such as social dilemmas, where different group members, or groups as opposed to individual members, have different preferences. Steiner's examples of interactive group tasks are of the cooperative variety, but differ in their respective degrees of cognitive interdependence they impose on its members. Conjunctive and disjunctive tasks are end points on a spectrum of how many members must succeed for the group to succeed. A disjunctive task, for example, would be a group of software engineers trying to identify

a bug in a computer program. Here, the role of social interactions is mostly a matter of convincing the group to adopt the correct solution once it has been found by any one of its members. A conjunctive task would be a group of software engineers frantically typing up source code to meet an impending deadline, which requires that everybody works as fast and error-free as possible. In other words, a disjunctive task is one in which the quality of group performance depends on that of its most capable member, whereas a conjunctive task is one in which it is constrained by that of its least capable member. In addition, Steiner also identified a class of relatively unstructured tasks that can be completed by a variety of combination schemes, to be chosen at the discretion of the group. An example of a *discretionary* task would be the improvised performance of a jazz trio, or the corporate design of a new advertisement campaign.

The disjunctive–conjunctive continuum also corresponds to the spectrum of social combination models or decision schemes, which are formalized models of group processes that assign probabilities to each group response given all possible distributions of member preferences (Stasser, 1999). For example, a *minimal quorum* (“truth wins”) assumes that a group response is correct if at least one member’s response is correct (disjunctive), a *quorum of two* (“truth-supported wins”) requires at least two correct responses, and *unanimity* requires that all members are correct (conjunctive). Other commonly used social decision schemes include *majority*, *proportionality*, or *delegation*. They provide an important class of baseline models which can be tested against actual group performance.

Based on his taxonomy, Steiner conceptualized the potential productivity of a group in terms of individual member resources and the demands of the group task. He recognized that groups often fail to achieve their full potential due to faulty group processes, and distinguished two main types of *process losses*. Motivation losses generally occur if members make a less than optimal contribution, either due to social loafing, free riding, or perhaps for selfish, competitive reasons. Coordination losses occur because of a less than optimal integration of individual members’ contributions, such as when a group fails to acknowledge a correct solution proposed by one of its members. Even though process losses are very common, it is also possible for groups to exceed their potential, contrary to Steiner’s pessimistic assessment. For example, since success in a conjunctive task is contingent on the performance of its weakest link, the proficiency of a group can often be improved by assigning different members to particular subtasks that fit best with their expertise, provided that the original task is divisible. This effectively turns a conjunctive task into what Steiner (1966) called a *complementary* task, in which group members collaboratively pool their diverse pieces of knowledge, skills, and resources into a single, collective outcome. Examples of complementary group performances with high levels of collaboration and cognitive interdependence include an orchestra performing a symphony, a football team running a play, or the police investigation of a crime scene.

The power of complementary problem solving is captured by the Gestalt maxim that “the whole is greater than the sum of its parts.” It implies that a group may collectively achieve something that could not have been done by any single member – even the most capable – working alone, nor by the sum of members working individually towards the same outcome. Such an outcome is also known as an *assembly bonus effect* (Collins and Guetzkow, 1964; Larson, 2010). It exemplifies the broader concept of *synergy*, which occurs whenever the joint outcome of two or more interacting parts of a system differs from the aggregated outcome of the parts operating independently (Corning, 2003).

Based on these considerations, *group cognition* can be defined as the collaborative performance of cognitive tasks such as remembering, problem solving, decision making, or verbal creativity for the purpose of producing a group-level outcome. Importantly, our use of the term does not directly refer to any particular quality of the group-level outcome, such as the collective verdict

of a jury, the co-authored publication of a scientific discovery, or the joint performance of an improvised dialogue. Those outcomes may be the result of group cognition, but they are not intrinsically “group-cognitive.” Instead, the defining feature of group cognition is the *collaborative interdependence* among cognizing group members – that is, it concerns emergent modes of organization by which the actions, ideas, and resources of individuals are coordinated, combined, and integrated into a group-level outcome (Theiner and O’Connor, 2010). The *emergent* character of group cognition can be understood as a failure of *aggregativity* in the sense of Wimsatt (1986). Wimsatt argued that properties of systems that are *aggregative* satisfy the following conditions: they (1) are invariant relative to the rearrangement of parts, (2) remain qualitatively similar under the addition or subtraction of parts, (3) are invariant relative to rearranging the parts into different subgroups, and (4) are not affected by any cooperative or inhibitory interactions among the parts. Many interesting phenomena that we would intuitively classify as instances of group cognition violate three or even all four of Wimsatt’s diagnostic criteria (Theiner, Allen, and Goldstone, 2010; Theiner, 2013). In what follows, I discuss several research paradigms which have contributed to our understanding of group cognition in this sense.

Groups as decision-making units

There has been a growing trend in small-group research to consider collaborative groups as cognitive units in their own right (Wittenbaum *et al.*, 2004). This conception is based on a functional analysis of the steps or processes that groups generally follow in the course of producing a specified group-level cognitive outcome. For example, a standard functional model of group decision making involves a sequence of four main steps (Forsyth, 2006): (i) an *orientation* phase, during which a group has to define the problem, set its goals, and plan out its procedures, (ii) a *discussion* phase, during which a group needs to gather, exchange, analyze, and weigh information, (iii) a *decision* phase, during which a group has to map members’ inputs into a collective solution based on one or more social decision schemes, and (iv) an *implementation* phase, in which the decision is put into action, and its impacts are being assessed. Based on this analysis, the main goal is then to describe in detail the cognitive, social, and communicative mechanisms by which these decision functions are carried out, and to identify the conditions under which groups tend to perform better than individuals. Taking a *collective information-processing* approach to group decision making implies that during the discussion stage, which is arguably the most critical part of the process, groups can benefit from improving their memory, by increasing their information exchange, and by processing information more thoroughly (Larson and Christensen, 1993; Hinsz, Tindale, and Vollrath, 1997; Propp, 1999). Each of these implications has been the subject of experimental research in social and organizational psychology.

Transactive memory

The ability of dyads and small groups to expand their collective memory capabilities through a division of mnemonic labor has been studied in the literature on *transactive memory* (Wegner, 1986; Ren and Argote, 2011). For example, one partner of a long-standing couple may remember how to procure their favorite food and pay their bills, while the other knows how to maintain their home security system and prepare their joint tax return. By cooperatively allocating the tasks of encoding, storing, modifying, and recalling task-relevant information among members with specialized abilities or knowledge, groups can build transactive memory systems (TMSs) that are greater than the sum of individual memory systems. The integrated functioning

of a differentiated TMS requires that group members develop a shared set of higher-order (“transactive”) memories for keeping track of who knows what, and for trusting each other’s expertise. For example, transactive memories are used for determining how, and in what format incoming information ought to be stored in a group, and for cueing the recognized experts whenever an interactive information search is executed.

Research has shown that collaborating groups remember more than their average or even their best single member, but often remember less than same-sized collections of non-interacting individuals (Weldon and Bellinger, 1997; Harris, Barnier, and Sutton, 2013). The most common explanation for the occurrence of such *collaborative inhibition* is that hearing others recall disrupts individuals’ idiosyncratic mnemonic strategies (Basden, Basden, Bryner, and Thomas, 1997). The detrimental effects of group recall can be reduced, or even reversed, by the choice of decision schemes such as consensus which invite more collaborative forms of error checking, the skilful deployment of collaborative practices as found in teams of expert pilots remembering aviation-related scenarios, or when group members are actively encouraged to develop joint retrieval strategies during a period of shared encoding, especially when the material to be remembered is emotionally meaningful to the group (Harris *et al.*, 2013).

The search for assembly bonus effects is sometimes hampered by a one-sided understanding of the purposes which the activity of shared remembering fulfills for real-world groups. What is tested in many studies of transactive memory is the ability of groups to optimize the amount or accuracy of recall. This creates an incentive for members to remember different items, which rewards the development of differentiated transactive memory structures. However, an equally important function of collaborative remembering is to reinforce the social bonds among its members, by merging disparate memories into a stable rendering of shared past experiences (Hirst and Manier, 2008). This creates an incentive for members to remember the same information, which rewards the development of assimilated transactive memory structures. Viewed from this perspective, the relevant assembly bonus of group memory consists in the joint construction of collectively shared memories that more effectively support the enduring social identity of a group. Consistent with this more flexible interpretation of group memory is Hollingshead’s (2001) proposal that the formation of a TMS is driven by the two fundamental processes of *cognitive interdependence*, which is a function of the extent to which each individual’s contribution depends on those of others, and *convergent expectations*, which is a shared conception of what each member ought to do to achieve a positive group outcome (Harris, Keil, Sutton, Barnier, and McIlwain, 2011; Theiner, 2013).

Collective information sampling

The superiority of groups as decision makers is often justified with the idea that by pooling the resources of its members, groups can take into account far more information than any one of its members. However, research shows that groups are strongly biased towards discussing information that is already shared, and consistently underutilize information that is known only to a few (Wittenbaum *et al.*, 2004). Because of this bias, groups frequently fail to recognize superior decision alternatives that would require the integration of critical yet unshared information. This so-called *hidden profile* effect has been replicated under many experimental conditions, and is surprisingly robust (Stasser and Titus, 2003). It is stronger in groups that are working on judgmental rather than intellectual tasks, and more pronounced when their members are under the impression that they lack sufficient information to make a fully informed decision.

The bias towards shared information reflects the double purposes of group discussions, which serves both informational and normative purposes. From a purely informational standpoint, one

would expect that groups who are striving to make the best possible decision would primarily sample information that is unevenly distributed among its members. But concomitant desire for reaching a consensus, getting closure, or convincing others to adopt their own views counteracts that tendency. In addition, individual members may selectively withhold information to gain a competitive advantage over others, or to impress others by feigning agreement. The latter influence can be particularly hard to overcome, because people tend to rely on the exchange of shared information as a reliable social indicator of members' competence and task credibility. Consequently, since information that is unshared cannot be used to validate one another's expertise, group discussants will tend to rehash points that are already common knowledge, thus further diminishing the group's chance of discovering a hidden profile.

A variety of interventions have been shown to improve a group's attention to unshared information. For example, being designated an "expert" on some topic made it more likely for that person to contribute unique information in her designated area of expertise, and for her contribution to be acknowledged by the group. It is also known that senior group members, who usually enjoy a higher social status, are more likely to bring up, as well as repeat information that is unshared. Other methods of avoiding the bias include increasing the diversity of opinions, emphasizing the importance of dissent, priming members with counterfactual thinking, introducing group discussion as a new order of business rather than a return to previously discussed material, and the use of computer-mediated decision support systems to display, access, and collaboratively modify the total stock of knowledge that is available to the group as a whole (Forsyth, 2006).

Collective induction

Groups not only have the potential to recall and exchange information more effectively than individuals, but to process information more deeply by evaluating the strengths and weaknesses of different options, correcting each other's errors, and integrating diverse viewpoints. *Collective induction* is the cooperative search for generalizations or rules which require groups such as scientific research teams, auditing teams, or air crash investigators to undergo a cycle of hypothesis generation and testing (Laughlin, 1999). Collective induction is a divisible and complementary task in which groups have the potential to collectively perceive patterns, propose and reject hypotheses, and arrive at interpretations that none of their members would have achieved individually.

Laughlin (1999) outlines a theory of collective induction which synthesizes a series of experiments in which groups had to induce a rule that partitions ordinary playing cards into examples and non-examples of the rule (e.g. "two diamonds alternate with two clubs") in as few trials as possible. Laughlin's rule-induction task has both intellectual and judgmental components: non-plausible hypotheses may be demonstrated to be incorrect, but plausible hypotheses may not be demonstrated to be uniquely correct vis-à-vis other competitors. Given enough information and time, groups performed at the level of the best of an equivalent number of individuals. The best fit of social combination models with actual group performance indicates that: (1) if at least two members propose demonstrably correct and/or plausible hypotheses, the group selects among those only; otherwise, it selects among all; (2) if a majority of members proposes the same hypothesis, the group applies majority voting; otherwise, it takes turns among the proposed alternatives, and formulates an emergent hypothesis that was not proposed by any member with probability $1/(H + 1)$, where H is the number of group members. The experiments also revealed that collective induction improved more by increasing evidence than

by increasing the number of hypotheses, and positive tests (examples) provide better evidence than negative tests (non-examples).

Subsequent work showed that groups of size three working on complex letter-to-numbers decoding problems were able to outperform even the *best* of a same-sized equivalent of independent individuals (Laughlin, Bonner, and Miner, 2002; Laughlin, Zander, Knievel, and Tan, 2003). Correct answers to these problems could be demonstrated by experimenter feedback, arithmetic, algebra, logical reasoning, or knowledge of certain number-theoretic properties. Because of the highly intellectual nature of the task, there was a clear-cut way for members to recognize answers that were correct, and to reject erroneous responses. By combining different types of reasoning strategies to solve letter-to-numbers problems, groups were better at solving the task according to a complementary model, rather than by selecting the single best-member solution according to a disjunctive model (Laughlin, 2011).

Groups as distributed cognitive systems

The “distributed cognition” framework was pioneered in the mid-to-late 1980s by Edwin Hutchins as a new way of studying cognition (Perry, 2003). Contrary to traditional cognitive science, where cognition is equated with information processing at the level of the individual mind/brain, it analyzes collaborative work practices which are often heavily mediated by the use of technology and the physical layout of the workspace as distributed cognitive systems in their own right. The key to this outward extension is a functional conceptualization of cognitive processes in terms of the *propagation of representational states across different media* (Hutchins, 1995). The term *media* is understood broadly to encompass both covert representations formed inside a person’s head, but also overt representations which are physically embodied in verbal exchanges, bodily gestures or movements, or artifacts such as maps, charts, tools, instruments, or computer displays. By focusing on the coordination mechanisms supporting the collaborative creation and transformation of representational states in the performance of various cognitive functions – rather than on any intrinsic substrate of cognition – the distributed cognition approach does not posit a deep gulf between mental/physical, individual/social, and cognitive/cultural resources. Instead, cognitive processes can be viewed as extending seamlessly across the traditional metaphysical boundaries between subjects and objects.

More specifically, cognitive processes can be distributed in at least three dimensions (Hollan, Hutchins, and Kirsh, 2000). First, cognitive processes may be distributed across the members of a social group. This means that the social organization of a group – together with the material structure of the environment in which it operates – can itself be seen as a form of cognitive architecture determining the patterns of information propagation. Conversely, it also means that the concepts and models used to describe socially distributed systems may also be fitting to describe the distributed organization of individual minds (Minsky, 1986). Second, cognitive processes can be distributed across neural, bodily, and environmental resources. In particular, work materials such as a blind man’s cane, a cell biologist’s microscope, or a mathematician’s calculator can become so deeply integrated into one’s cognitive processing, by scaffolding the structure of a task and even providing active sources of information processing, that they are more properly viewed as parts of an extended cognitive system, rather than as mere stimuli or passive external memory resources for a disembodied mind (Clark, 2008). Finally, cognitive processes may be distributed through time, such that the products of earlier events can greatly transform the task demands at subsequent stages of processing. From this perspective, culture can be seen as a potent, cumulative reservoir of resources for learning, problem solving, and reasoning, “ratcheting” up the collective insights of previous generations so individuals do not

have to start from scratch. Taken together, the mediating effects of the social, technological, and cultural distribution of labor imply that the cognitive properties of groups may differ significantly from those of individuals.

The proper investigation of distributed cognitive systems requires an interdisciplinary kind of “cognitive ethnography” based heavily on participant observation, which brings together and refines many different techniques for capturing the richly embodied, socially embedded, and often surprisingly opportunistic nature of meaningful human activity in real-world settings. These observations provide naturalistic data that can be further tested by conducting more constrained experiments and developing formal models, but they also lead to concrete proposals for improving the design of cognitive artifacts and workplaces, which ultimately feed back into the process of theory construction. Detailed studies of distributed cognition “in the wild” include diverse collaborative activities performed by maritime navigation crews (Hutchins, 1995), emergency/rescue management operations (Garbis and Waern, 1999), theatrical practices in Elizabethan drama (Tribble, 2005), bioengineering labs (Nersessian, 2006), and crime scene investigation (Baber, Smith, Cross, Hunter, and McMaster, 2006).

Groups as complex adaptive systems

Many group-living species such as ants, fish, and humans display adaptive, remarkably robust forms of coordinated collective behavior that seem to arise spontaneously, in non-supervised fashion, in response to environmental changes. For example, to avoid a predator attack, a school of fish flees almost simultaneously, in near perfect synchrony, as if it was collectively sensing the imminent danger, even though there is no external blueprint or centralized controller who broadcasts instructions of how to respond. Instead, the adaptive group response results from the dynamic self-organization of large collections of partially connected agents, following relatively simple behavioral rules. Those agents interact either directly, through various sensory channels, or indirectly, by leaving stigmergic traces in the environment that can be sensed by others (Moussaid, Garnier, Theraulaz, and Helbing, 2009; Goldstone and Gureckis, 2009; Miller and Page, 2007).

A frequently cited example of self-organized collective information processing through indirect communication is the formation of foraging trails in ant colonies (Moussaid *et al.*, 2009). When a single ant randomly stumbles across a new food source, it drops pheromones on its way back to the nest. The attractive influence of pheromones will cause nearby ants to modulate their random exploratory behavior towards the trail, which increases their chances of locating the same food source. This creates a positive feedback loop: as more ants are recruited to a given source, the concentration of pheromones increases, which in turn further increases the attractiveness of the trail. The resulting non-linear amplification of the incipient trail is held in check by negative feedback processes such as the evaporation of the pheromones, the depletion of the food source, but also the availability of nearby foragers, all of which help to stabilize the flow of ants. In addition, ants also modulate their trail-laying intensity in proportion to the quality of the food. Faced with a choice between two unequal food sites, what may initially be only a slightly higher pheromone concentration left on the trail towards the richer source will quickly become magnified, directing the colony to focus almost exclusively on the more profitable option. The same reinforcement mechanism also allows colonies to discover the shortest path to an existing food source.

The interplay between amplification and dampening of information underlies the synchronized responses of flocking birds or schooling fish (Couzin, 2009). The social interactions among the members of a flock, for example, are governed by a few rules such as near-range

repulsion to maintain personal space, long-term attraction to ensure group cohesion, and a preference to align the direction of travel towards one's nearest neighbors. An external perturbation, such as the presence of a resource or a predator, may initially only be discovered by a small proportion of flockmates due to their limited sensory capabilities and crowded vision. However, the close behavioral coupling between nearest neighbors allows localized changes in movement to be amplified, and swiftly propagated through the flock. Hence, the flock as a whole forms a mobile, distributed perceptual system whose effective range exceeds that of any single member. Depending on the task demands, flocks can modify their interactions in context-sensitive ways. Under a threat of attack, individuals tend to align more strongly with one another, thus increasing the collective vigilance of the flock, though at the expense of causing false alarms. Conversely, since long-term migration requires that flocks are not too sensitive to local fluctuations in noisy, long-range resource gradients and to individual errors, birds adopt rules that favor social cohesion in order to facilitate a collective dampening of information.

Even though the self-organized dynamics of many forms of collective human behavior can often be modeled with surprisingly simple behavioral rules (Ball, 2004), the greater cognitive sophistication of humans introduces additional complexity that can interfere with collective dynamics. In particular, because people can quickly adopt new behavioral strategies in response to past experiences, novel behavioral conventions can emerge on much shorter timescales, for a larger variety of different settings, and in ways that are sensitive to cultural variations.

Group agency

In ordinary parlance, we often say that a government pursues ways to increase tax revenues, that a firm intends to release a new smartphone, or that a church opposes gay marriage. A literal attribution of agency to groups seems to imply that we consider groups as capable of having collective beliefs and desires, forming joint intentions, making evaluative judgments, managing their epistemic coherence through forms of collective reasoning that are robustly rational, and self-ascribing intentional attitudes from a first-person plural perspective (List and Pettit, 2011; Gilbert, 1989; Ludwig, 2007; Huebner, 2013). Drawing on a wide range of work on joint intentionality, social ontology, social choice theory, the sociology of collectives, and studies of collective responsibility and legal personhood, List and Pettit (2011) have forcefully argued that our concept of group agency cannot be reduced to that of individual agency, and indeed plays an indispensable causal-explanatory role in our ordinary as well as social-scientific discourse.

Their main argument against reduction is based on a logical paradox that arises when multi-member groups have to aggregate the distinct and possibly conflicting sets of intentional attitudes of its members into a single system of collective attitudes that is endorsed by the groups as a whole. In analogy to Arrow's (1951/1963) more widely known impossibility theorem about preference aggregation, List and Pettit (2002) have shown that there can be no judgment aggregation function that (i) accepts as input any possible profile of member attitudes (*universality*), (ii) produces a consistent and complete group output (*rationality*), (iii) gives all members equal weight in determining the outcome (*anonymity*), and (iv) is *systematic*, that is, the group attitude on each judgment depends only on members' attitudes towards that very judgment (*independence*), and that the same pattern of dependence between individual and collective attitudes is accepted for all judgments (*neutrality*). More constructively, this means that groups which seek to form collective attitudes must relax at least one of these four conditions.

List and Pettit suggest that the most promising organizational design in response to this dilemma is to lift systematicity, in particular independence, by prioritizing some judgments over others, and letting the group attitudes on the first set determine those of the second (without

giving individuals any further say). This way of “collectivizing” reason most clearly reflects the purposes of a reason-driven collective agent, because it implies that coherent group outcomes can only be purchased at the expense of individual rationality. In addition, by further lifting anonymity, groups can implement distributed decision-making procedures in which different subgroups are assigned to “fix” the group’s attitudes on specific judgments. Adopting the former procedure shows that a group’s attitude cannot be derived in a strict, proposition-wise fashion from members’ attitudes, and adopting the latter procedure also introduces heterogeneity because different members play different roles in determining the group outcome. Taken together, the fact that individual and group attitudes can come apart in surprising ways further underscores the theoretical autonomy of group agency.

References

- Allport, G. W. (1968). The historical background of modern social psychology. In G. Lindzey and E. Aronson (Eds.), *The handbook of social psychology* (2nd ed., Vol. 1, pp. 1–80). Reading, MA: Addison-Wesley.
- Arrow, K. J. (1951/1963). *Social choice and individual values*. New Haven, CT: Yale University Press.
- Baber, C., Smith, P. A., Cross, J., Hunter, J., and McMaster, R. (2006). Crime scene investigation as distributed cognition. *Pragmatics and Cognition*, 14, 357–85.
- Ball, P. (2004). *Critical mass: How one thing leads to another*. New York: Farrar, Straus & Giroux.
- Barnier, A. J., Sutton, J., Harris, C. B., and Wilson, R. A. (2008). A conceptual and empirical framework for the social distribution of cognition: The case of memory. *Cognitive Systems Research*, 9, 33–51.
- Basden, B. H., Basden, D. R., Bryner, S., and Thomas, R. L. (1997). A comparison of group and individual remembering: Does collaboration disrupt retrieval strategies? *Journal of Experimental Psychology: Learning, Memory and Cognition*, 23, 1176–89.
- Bettencourt, L. M. A. (2009). The rules of information aggregation and emergence of collective intelligent behavior. *Topics in Cognitive Science*, 1, 598–620.
- Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. New York: Oxford University Press.
- Collins, B. E., and Guetzkow, H. (1964). *A social psychology of group processes for decision-making*. New York: Wiley.
- Corning, P. A. (2003). *Nature’s magic: Synergy in evolution and the fate of humankind*. New York: Cambridge University Press.
- Couzin, I. D. (2009). Collective cognition in animal groups. *Trends in Cognitive Sciences*, 13, 36–43.
- Forsyth, D. (2006). *Group dynamics* (5th ed.). Belmont, CA: Wadsworth.
- Garbis, C., and Waern, Y. (1999). Team co-ordination and communication in a rescue command staff: The role of public representations. *Le Travail Humain*, 62, 273–91.
- Gilbert, M. (1989). *On social facts*. London: Routledge.
- Goldstone, R., and Gureckis, T. (2009). Collective behavior. *Topics in Cognitive Science*, 1, 412–38.
- Harris, C. B., Barnier, A. J., and Sutton, J. (2013). Shared encoding and the costs and benefits of collaborative recall. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 39, 183–95.
- Harris, C. B., Keil, P. G., Sutton, J., Barnier, A., and McIlwain, D. (2011). We remember, we forget: Collaborative remembering in older couples. *Discourse Processes*, 48, 267–303.
- Hinsz, V. B., Tindale, R. S., and Vollrath, D. A. (1997). The emerging conceptualization of groups as information processors. *Psychological Bulletin*, 121, 43–64.
- Hirst, W., and Manier, D. (2008). Towards a psychology of collective memory. *Memory*, 16, 183–200.
- Hollan, J., Hutchins, E., and Kirsh, D. (2000). Distributed cognition: Toward a new foundation for human-computer interaction research. *ACM Transactions on Computer-Human Interaction*, 7, 174–96.
- Hollingshead, A. B. (2001). Cognitive interdependence and convergent expectations in transactive memory. *Journal of Personality and Social Psychology*, 81, 1080–89.
- Huebner, B. (2013). *Macro cognition: A theory of distributed minds and collective intentionality*. New York: Oxford University Press.
- Hutchins, E. (1995). *Cognition in the wild*. Cambridge, MA: MIT Press.
- Isaacson, W. (2004). *Benjamin Franklin: An American life*. New York: Simon & Schuster.
- Larson, J. R. (2010). *In search of synergy in small group performance*. New York: Psychology Press.

- Larson, J. R., and Christensen, C. (1993). Groups as problem-solving units: Toward a new meaning of social cognition. *British Journal of Social Psychology*, 32, 5–30.
- Laughlin, P. R. (1980). Social combination processes of cooperative problem-solving groups on verbal intellectual tasks. In M. Fishbein (Ed.), *Progress in social psychology* (pp. 127–55). Hillsdale, NJ: Erlbaum.
- (1999). Collective induction: Twelve postulates. *Organizational Behavior and Human Decision Processes*, 80, 50–69.
- (2011). *Group problem solving*. Princeton: Princeton University Press.
- Laughlin, P. R., Bonner, B. L., and Miner, A. G. (2002). Groups perform better than the best individuals on letters-to-numbers problems. *Organizational Behavior and Human Decision Processes*, 88(2), 605–20.
- Laughlin, P. R., Zander, M. L., Knivel, E. M., and Tan, T. K. (2003). Groups perform better than the best individuals on letters-to-numbers problems: Informative equations and effective strategies. *Journal of Personality and Social Psychology*, 85(4), 684–94.
- List, C., and Pettit, P. (2002). Aggregating sets of judgments: An impossibility result. *Economics and Philosophy*, 18, 89–110.
- (2011). *Group agency: The possibility, design, and status of corporate agents*. Oxford: Oxford University Press.
- Ludwig, K. (2007). Collective intentional behavior from the standpoint of semantics. *Noûs*, 41(3), 355–93.
- Miller, J. H., and Page, S. E. (2007). *Complex adaptive systems: An introduction to computational models of social life*. Princeton: Princeton University Press.
- Minsky, M. L. (1986). *The society of mind*. New York: Simon & Schuster.
- MIT Center for Collective Intelligence (n.d.). *Handbook of collective intelligence*. MIT Center for Collective Intelligence website. Retrieved from <http://scripts.mit.edu/~cci/HCI/index.php>
- Moussaid, M., Garnier, S., Theraulaz, G., and Helbing, D. (2009). Collective information processing and pattern formation in swarms, flocks, and crowds. *Topics in Cognitive Science*, 1, 469–97.
- Nersessian, N. J. (2006). The cognitive-cultural systems of the research laboratory. *Organization Studies*, 27(1), 125–45.
- Perry, M. (2003). Distributed cognition. In J. M. Carroll (Ed.), *HCI models, theories, and frameworks: Toward an interdisciplinary science* (pp. 193–223). San Francisco: Morgan Kaufmann.
- Propp, K. (1999). Collective information processing in groups. In L. Frey, D. S. Gouran, and M. S. Poole (Eds.), *Handbook of group communication theory and research* (pp. 225–50). Thousand Oaks, CA: Sage.
- Ren, Y., and Argote, L. (2011). Transactive memory systems 1985–2010: An integrative framework of key dimensions, antecedents, and consequences. *Academy of Management Annals*, 5, 189–229.
- Stasser, (1999). A primer of social decision scheme theory: Models of group influence, competitive model-testing, and prospective modeling. *Organizational Behavior and Human Decision Processes*, 80(1), 3–20.
- Stasser, G., and Titus, W. (2003). Hidden profiles: A brief history. *Psychological Inquiry*, 14, 304–13.
- Steiner, I. D. (1966). Models for inferring relationships between group size and potential group productivity. *Behavioral Science*, 11, 273–83.
- (1972). *Group process and productivity*. New York: Academic Press.
- Surowiecki, J. (2004). *The wisdom of crowds: Why the many are smarter than the few and how collective wisdom shapes business, economies, societies and nations*. New York: Little, Brown.
- Theiner, G. (2013). Transactive memory systems: A mechanistic analysis of emergent group memory. *Review of Philosophy and Psychology*, 4, 65–89.
- Theiner, G., Allen, C., and Goldstone, R. (2010). Recognizing group cognition. *Cognitive Systems Research*, 11, 378–95.
- Theiner, G., and O'Connor, T. (2010). The emergence of group cognition. In A. Corradini and T. O'Connor (Eds.), *Emergence in science and philosophy* (pp. 78–117). New York: Routledge.
- Tribble, E. B. (2005). Distributing cognition in the globe. *Shakespeare Quarterly*, 56, 135–55.
- Wegner, D. M. (1986). Transactive memory: A contemporary analysis of the group mind. In B. Mullen and G. R. Goethals (Eds.), *Theories of group behavior* (pp. 185–208). New York: Springer.
- Weldon, M. S., and Bellinger, K. D. (1997). Collective memory: Collaborative and individual processes in remembering. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 23, 1160–75.
- Wilson, R. (2004). *Boundaries of the mind: The individual in the fragile sciences; Cognition*. Cambridge: Cambridge University Press.
- Wimsatt, W. C. (1986). Forms of aggregativity. In M. G. Grene, A. Donagan, A. N. Perovich, and M. V. Wedin (Eds.), *Human nature and natural knowledge* (pp. 259–91). Dordrecht: Reidel.
- Wittenbaum, G. M., Hollingshead, A. B., Paulus, P. B., Hirokawa, R. Y., Ancona, D. G., Peterson, R. S., Jehn, K. A., and Yoon, K. (2004). The functional perspective as a lens for understanding groups. *Small Group Research*, 35(1), 17–43.

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PART VI

Meta-topics

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34

COGNITION

Gary Hatfield

Introduction

The study of cognition was widespread in experimental psychology after behaviorism's decline and was a reason for the decline. A specific notion of cognition was central to the rise of the interdisciplinary program of cognitive science. The perceptual psychologist James J. Gibson thought that postulation of cognitive processes should be avoided. Cognition, as knowledge, has long been studied in philosophy. Nowadays, cognitive psychology and cognitive science come in various flavors, including classical, connectionist, dynamic, ecological, embodied, embedded, enactive, and extended. These flavors differ in their conceptions of cognition and on the roles of the body and the environment in cognitive processes.

But what is cognition? What makes a process cognitive? These questions have been answered differently by various investigators and theoretical traditions. Even so, there are some commonalities, allowing us to specify a few contrasting answers to these questions. The main commonalities involve the notion that cognition is information processing that explains intelligent behavior. The differences concern whether early perceptual processes are cognitive, whether representations are needed to explain cognition, what makes something a representation, and whether cognitive processes are limited to the nervous system and brain or include other bodily structures or the environment itself.

After unearthing some root notions of cognition in the development of cognitive psychology and cognitive science, this chapter considers the commonalities and differences just scouted, examines Wheeler's (2005) reference to Descartes' works in describing "Cartesian" cognitive theory, finds the real target of situated approaches in classical symbolic cognitive science, and suggests that instead of revisiting that target attention should turn to characterizing the varieties of intelligent (adaptive, appropriate, flexible) behavior.

Some root notions of cognition

Bernard Baars (1985), in his excellent study of the "cognitive revolution," describes cognitive psychology as a metatheory that supplanted the previous behavioristic metatheory. Behaviorism was many splendored. It came in Watsonian, Hullian, Tolmanian, and Skinnerian varieties. All agreed that behavior provides the evidence and object of explanation for psychology, and all but

Tolman excluded mentalistic terms in describing and explaining that behavior. Tolman allowed intentionality, Gestalt principles of perceptual organization, and representational cognitive maps (Hatfield, 2003).

By the 1950s, Hullian learning theory, which was deeply theoretical (positing non-mentalistic inner states), was in retreat; and Skinner's "hollow organism" behaviorism, which shunned internal states in psychological explanation, was ascendant. Against both Hull and Skinner, some psychologists – sometimes in league with computer scientists and linguists, and sometimes extending ongoing work (from earlier in the century, including that of Gestalt psychology) in perception, attention, and memory – began to posit internal states described in terms of information processing or information flow. In Baars's (1985) account, these psychologists used behavioral data to infer unobservable internal constructs, such as "purposes," "ideas," "memory," "attention," and "meaning" (pp. 7, 144). Psychologists came to speak of "representations" that organisms have of themselves and their world, and they construed the transformation of such representations as "information processing" (p. 7). Such internal representations were only reluctantly described as "conscious" or as subject to introspection (pp. 169, 414).¹ Starting from Baars's portrayal, we can distinguish several conceptions of cognition in the literature.

Cognitive mechanisms and information processing

In 1967, Ulric Neisser published a signal work entitled *Cognitive Psychology*. It included two major parts, on visual and auditory cognition, and a brief part on higher mental processes. Neisser offered two glosses on the term "cognitive psychology," indicating a broader and a narrower conception of cognition. In a broad sense, cognitive psychology studies the "cognitive mechanisms," which include perception, pattern recognition, imagery, retention, recall, problem solving, concept formation, and thinking (Neisser, 1967, pp. 4, 10, 11). In a narrow sense, Neisser promoted a certain conception of cognition as "the flow of information in the organism," including many transformations and reconstructions of that information (pp. vii, 208). In his view, "Whatever we know about reality is mediated, not only by the organs of sense but by complex systems which interpret and reinterpret sensory information" (p. 3). His cognitive psychology largely focused on visual and auditory information processing. He described such processing as yielding not only behavior but also "those private experiences of seeing, hearing, imagining, and thinking to which verbal descriptions never do full justice" (p. 3). His book refers to behavioral data but also describes perceptual experiences. Although not labeling these as "conscious," he clearly included conscious experience among the discussables.

By contrast with theories to come, I should note that Neisser was aware of comparisons between human cognition and digital computers and found comparing human processes with computer programs to be useful but limited; he expressed deep skepticism of AI (artificial intelligence) models, such as that of Newell, Shaw, and Simon (1958), and, by his own account, largely put them aside (Neisser, 1967, p. 9). Neisser's cognitive psychology invoked psychological processes of construction and synthesis, which were characterized in task-specific terms. His heroes included especially Bartlett (1932, 1958), who worked on memory, but also Broadbent (1958), who worked on attentional constraints in auditory perception, and Bruner, who worked on concept formation (Bruner, Goodnow, and Austin, 1956).

Neisser's approach (1967, pp. 304–5) did not focus on explaining the behavior of human beings freely acting "in the wild" (i.e. outside the laboratory). Rather, he aimed to discover information-processing mechanisms by inferring their characteristics from the available data. This information-processing approach to psychology, which sees its subject matter as the information-processing mechanisms underlying perception, attention, recognition, categorization,

memory, learning, problem solving, thinking, and speech, became entrenched. Often, information processing was itself the root notion (Lindsay and Norman, 1972; Massaro, 1989), and “cognition” (a term these authors used sparingly) was distinguished from perception as pertaining to the processes in recognition, problem solving, and memory. This runs counter to Neisser’s conception of cognitive psychology as concerned with all information processing, including perception. Neisser’s conception lives on, as seen in Dawson (1998) and Eysenck and Keane (2000), but with a difference: the conception of information processing is now allied to computation.

Cognition as symbol processing

Comparisons with computers as information handling devices were not uncommon in the 1950s and 1960s. With the formulation of Fodor’s (1975) language-of-thought hypothesis, the computer analogy became the foundation of a new, interdisciplinary enterprise soon to be called “cognitive science” (e.g. Collins, 1977). Fodor’s approach was to extract a common set of computational assumptions from recent work in cognitive psychology and psycholinguistics. His main examples were rational choice, concept learning, perceptual belief, and language learning. In his terms, such theories involved computations defined over symbolic representations. (Actually, he would have considered “symbolic representation” to be redundant, since he unceremoniously treated the terms as interchangeable; Fodor, 1975, p. 55.)

Fodor grounded his notion of symbol through a comparison with the machine language in a standard digital computer. Humans are “built to use” their native language of thought (Fodor, 1975, p. 66). Empirically, we know we have the right computational theories when inputs and outputs line up with stimuli and with responses as described in subjects’ propositional attitudes (pp. 74–75). The posited internal formulae should line up with a subject’s beliefs or other intentional states. A cognitive theory “tries to characterize the ways in which the propositional attitudes of an organism are contingent upon its data processes, where ‘data processes’ are sequences of operations upon formulae of the internal language” (p. 77). Standard or “classical” cognitive science was born.

John Haugeland soon clarified the object and the structure of explanation of “cognitivism” (1978) or “cognitive science” (1981). As he put it: “The basic idea of cognitive science is that *intelligent beings are semantic engines* – in other words, automatic formal systems with interpretations under which they consistently make sense” (Haugeland, 1981, p. 31). Haugeland here endorses symbolic computationalism, imputing a formal system under an interpretation to cognitive systems. The formal system, like that in a computer, can be characterized wholly in syntactic terms. In a theory of cognition, the theorist assigns an interpretation to the computational states of the posited system which “makes sense of” the organism’s behavior in relation to its situation (pp. 28–33). That is, the theorist proposes that states of the system intrinsically have certain meanings or contents.² Haugeland also expresses a conception of cognition that has become widespread: cognition is what supports intelligent behavior.

Computation and representation without symbol systems

In the early days of classicism, David Marr (1982) proposed a useful way of thinking about perceptual and cognitive processes. He distinguished three levels of analysis: computational, algorithmic, and implementational. The “computational” level essentially was a task analysis: it specifies what task the given perceptual or cognitive system is supposed to fulfill in the organism. The algorithmic level proposes concrete processing operations that, in models of vision (Marr’s target), would operate on optical inputs and transform them into a representation of the distal

scene. Finally, the implementational level is the hardware realization of the processing operations. His approach also charted the employment in the visual system of environmental regularities, such as that surfaces are comparatively smooth.

Marr (1982, p. 343) thought of the algorithms and their implementation in classical, symbolist terms. But he need not have done so. His three-level analysis allowed others to propose alternative schemes for thinking about algorithms and implementation. Theories of vision had long postulated operations to combine information. While some theorists, such as Irvin Rock (1975), conceived of these operations as inferential (and carried out in a language-like, albeit insulated, system of representations; Rock, 1983, p. 13), other theorists recognized that such operations might combine perceptual information, conceived in analog terms (e.g. as continuously varying magnitudes), without the benefit of cognitive and conceptual processes such as inference (Hatfield, 1988; see also Hatfield and Epstein, 1985, and Epstein, 1973). Processes that combine optical information for visual angle with a registered value for distance to yield size perception fit this bill, but so might mechanisms for recovering Gibsonian higher-order stimulus variables.

In 1984, Kosslyn and Hatfield proposed a connectionist interpretation as especially suited to perceptual processing, explicitly reinterpreting Marr's algorithms as non-symbolic but representational, with a neural-net or connectionist implementation. Such processing models might invoke rules of information-combination and notions of representations of proximal and distal states, without thinking of the rules as explicitly represented (as in symbolic models) or of the representations as syntactic (they might be analog). In a later terminology, the processing rules might be *instantiated* without being explicitly represented (Hatfield, 1991a, 1991b). Kosslyn and Hatfield also observed that Marr's "assumptions" about environmental regularities could be construed not as explicitly stated rules but as "engineering assumptions," by which they meant that "it is as if the system were engineered in such a way that it will work in environments where certain conditions are met" (Kosslyn and Hatfield, 1984, p. 1040).³

Connectionist models come in a variety of forms, associated with sometimes opposing conceptions of representation, such as local versus distributed representations (for an overview, see Bechtel and Abrahamsen, 1991). In models of early perceptual achievements, such as the creation of visual representations of shaped surfaces at a distance, connectionist networks can provide a happy medium for modeling rule-instantiating analog perceptual processes. The connectionist approach also has been applied to complex cognitive tasks such as language processing, using dynamical models that allow continuously varying magnitudes to serve as (subsymbolic) representations (Smolensky, 1988).⁴ Connectionism is not a specific approach but offers a family of model-types that enable various ways of thinking about perception and cognition without going symbolic from the start. Although such models are not essentially situated, it makes sense in thinking about connectionist processes to see them as adjusted to environmental regularities (Hatfield, 1988, 1990). Not having the symbolic metaphor to fall back on, such models may (or should) appeal to environmentally conditioned task analyses in grounding their notions of what is computed and what representations are needed.

Cognition as what supports intelligent behavior

The cognitive revolution entrenched the notion that cognitive processes are responsible for effective behavior. This idea is expressed by Bechtel and colleagues: "Cognitive science is the multidisciplinary scientific study of cognition and its role in intelligent agency. It examines what cognition is, what it does, and how it works" (Bechtel, Abrahamsen, and Graham, 1998, p. 3). As they make clear, this definition is broad enough to cover various conceptions of how cognition

works: classical, connectionist, and situated (pp. 91–92). Some of these approaches, under the umbrella of situated cognition, challenge the notion of cognition as information processing in the head. But such challengers retain a steady conception of what cognition does, which is “to enable agents to interact intelligently with their environments” (p. 92).

Recourse to the notion of “intelligent agency” (or the earlier “intelligent beings”) invites reflection on the notion of intelligence. The term plays a prominent role in discussion but is not found in the index or table of contents (except as “Artificial Intelligence” and “Unconscious Intelligence,” Bechtel and Graham, 1998, p. vi). The chapter on “Unconscious Intelligence” characterizes unconscious processes as “smart” or “intelligent” if they are “sophisticated, flexible, and adaptive” (Allen and Reber, 1998, p. 314). This description may exclude reflexes and also instincts (on many conceptions). Otherwise, it is open-ended, presumably including early visual processes that underlie the perceptual constancies and other sensory processes that are world directed, as well as action guidance, concept formation, emotion (at least cognitive theories of the emotions), problem solving, and reasoning.

When Haugeland (1981) spoke of cognitive processes as providing an account of intelligence, these processes were conceived as occurring between stimulus and response. Cognitive theories replaced behavioristic intervening variables with mentalistic ones. Those were at first symbolically conceived, but connectionism soon provided an alternative that also accommodated notions of representation and information processing. In the usual paradigms, cognition occurs between stimulus and response and does not consider the effects of responses on stimulation or take account of bodily organization, and only in some cases (including Marr) is put in relation to environmental regularities. As it happens, the push toward embodiment and environmental embeddedness originally came from a theorist who was anti-cognitivist.

Gibson and his impact: the importance of the environment

While the information-processing psychologists of the 1950s, 1960s, and 1970s were filling in between the sense organs and behavior (focusing on internal processes), Gibson was arguing that organisms are active in perceiving (1950), that sensory systems evolved to take into account environmental regularities (1966), and in favor of an ecological psychology in which the environment is described in organism-relative terms, yielding an “ecological physics” (1979). Gibson held that traditional theories of visual perception overlooked significant aspects of sensory information, including adequate information in the light to specify the distal environment. Consequently, he found no need to posit cognitive operations to supplement sensory information. He held that physiological mechanisms pick up information by “resonating” to it (Gibson, 1966, pp. 4–5), but he did not fill out the resonance analogy. Even if his view is not completely right (about either the information or the lack of need for psychological processes to recover it; Hatfield, 1988, 1990; Neisser, 1976), Gibson’s work directed attention to the tie between perception and action and the fact that an organism’s own activity in relation to the environment generates stimulus information (e.g. bodily motion in a direction creates optic flow that specifies that direction).

Gibson’s outlook spurred a substantial research tradition, including many who shared his anti-cognitivist outlook. Within this tradition, Turvey and his colleagues developed a dynamical systems approach to picking up Gibsonian information, which rejects any appeal to representations or traditional information processing. Nonetheless, they did offer a view of cognition. According to Turvey and Carello, “The term ‘cognition’ is taken, very generally, to refer to the

coordination of any organism (as an epistemic agent) and its environment (as the support for its acts). The task of cognitive theory is to explain this epistemic, intentional coordination of organism and environment” (1981, p. 313). Rejecting internal representations and unsecured attributions of intelligence, they emphasized Gibsonian realism, his commitment to organism–environment informational relations, an ecological scale of analysis, and appeal to dynamic physical systems to portray internal processes (thereby elaborating the resonance analogy). “Intentional” relations to the environment are reduced to informational relations between environment and organism. In a more recent overview, these authors conclude: “Consistent with a strategic approach to perception and action that minimizes (and, for all practical purposes, precludes) mental representations and computations, we have identified some dynamical themes that have been exploited in ecological research in haptic perception and coordinated movement” (Turvey and Carello, 1995, p. 396). The specific examples include visual–tactual coordination in learning to juggle and to use control levers. In this more recent survey, they avoid the term “cognition” altogether.

Gibson also influenced mainstream cognitivists to alter their conceptions so as to take account of embodiment, environmental embeddedness, and organismic action. In 1976, Neisser published a second book sounding these themes. He conceived perception as a cycle that incorporates action and in which cognitive schemata direct exploration of the environment and the sampling of present objects, which in turn alters the schemata as a result of the information acquired (Neisser, 1976, pp. 20–24). He thought of the processes by which the schemata direct exploration and incorporate information as cognitive. His definition of cognition was a bit general: “Cognition is the activity of knowing: the acquisition, organization, and use of knowledge” (p. 1). But his intent was clear: he wished to join a Gibsonian outlook with mentalistic notions from the information–processing tradition (p. 24). Marr, with his emphasis on ecologically valid environmental assumptions, was also deeply indebted to Gibson’s approach (Marr, 1982, pp. 29–31).

Fast-forwarding, theoretical outlooks that fall under the umbrella of situated cognition (dynamic, ecological, embodied, embedded, enactive, and extended) have proliferated. Among these, Gibsonian inspiration is often but not everywhere acknowledged. The notion of cognition remains that of the new mainstream: cognition supports intelligent behavior (Clark 2010, p. 92). Michael Wheeler (2005), from the extended cognition camp, has been especially explicit on the breadth that he desires in interpreting the notion of intelligence. He sees cognitive processing as yielding “displays of intelligence” that involve “behaving appropriately (e.g., adaptively, in a context-sensitive fashion) with respect to some (usually) external target state of affairs” (p. 3). The notions of “intelligence” and “cognition” are here used in a “deliberately broad and nonanthropocentric manner,” to include not only human capacities for reflective thought and conceptualization but also “cases in which an agent coordinates sensing and movement, in real time, so as to generate fluid and flexible responses to incoming stimuli” (ibid.). Animal cognition is included (e.g. tracking mates, avoiding predators). Action is intelligent, including navigating the terrain as an animal moves along. Cognition includes both “knowing that” and “knowing how” (p. 4). The processes that support intelligent behavior are conceived as dynamical systems, and only sometimes involve internal representations (see also van Gelder and Port, 1995, pp. 11–12).⁵

The core notion of cognition started as information processing and was then modified by differing models of how information is processed, including classical and connectionist visions. As work proceeded, the notion of cognition as supporting intelligent behavior gained currency.⁶ How it does so has been variously conceived. The past decade has seen rapid growth in conceptions of situated cognition.

Commonalities and differences in the notion of cognition

If one wanted a notion of the cognitive that could cover all the above usages, including Turvey and Carello (1981) and other non-representational dynamical systems approaches (e.g. Kelso, 1995; Chemero, 2009), it would have to be defined at the *molar* level, as a type of behavior of the whole organism. Cognitive behavior would be adaptive, appropriate, and flexible in relation to environmental and organismic circumstances.

There is something to be said for seeking to identify the forms of behavior that are cognitive at the molar level. However, it is more idiomatic to call such behavior “intelligent” than “cognitive.” This aspect of linguistic usage favors the notion that cognition is mental and that the mind is more than its behavioral expression. All the same, molar-level analyses of what makes behaviors intelligent or flexibly adaptive would be useful. This might have something of the feel of Ryle’s (1949) analysis of clever behavior, but without the added rider that there can be no intraorganismic explanation of the cleverness. With such a molar description in place, one might choose to use the term “cognitive” to describe the processes that explain intelligent behavior. It might then be best to restrict that term to those processes that involve mentalistic notions such as representation or mental content and that have a place in “cognitive mechanisms” such as those listed earlier (pp. 362–63).⁷ In this case, all of the above usages except that of Turvey and Carello (1981) and other non-representational dynamicists would be included.

Within this still quite large group, there are differences in what counts as cognition. Especially in the decades from the 1960s through the 1980s, a significant number of theorists distinguished perception from cognition. This occurred at two different levels of analysis. First, at the molar level, the perceptual theorist Rock distinguished “sensory processes” that constitute perception from “cognitive processes” (1975, p. 24). He assigned to the first group the formation of a perceptual object through the perception of shape, size, distance, direction, orientation, and rest or motion. The second category begins “where perception ends,” with “the perceived object,” and includes “recognition, recall, association, attention, abstraction, concept formation, understanding and meaningful learning, problem solving, and thinking” (*ibid.*). In this scheme, the cognitive and the conceptual go together. This sort of usage matches that of Lindsay and Norman (1972) and Massaro (1989), as previously noted.

Among those distinguishing perception from cognition, the second level of analysis concerns the character of the underlying processes that yield molar perception and cognition. Rock (1983), while maintaining a distinction between perceptual (in vision, picture-like) and cognitive (recognition) achievements, proposed that perception is mediated internally by inferential operations that might easily be labeled “cognitive.” For instance, he suggested that perceptual processes involve language-like, propositional descriptions that enter into deductive inferences (pp. 13, 240). Elizabeth Spelke (1988) argued the other way, that the processes underlying perception are essentially non-conceptual. For that reason, she assigns molar-level object perception to cognitive or conceptual processes, as when she says that “the apprehension of objects is a cognitive act, brought about by a mechanism that begins to operate at the point where perception ends” and brings concepts to bear (p. 199). I made the same alignment of “cognitive” with “conceptual” in Hatfield (1988), so that by “non-cognitive” processes I meant non-conceptual algorithms involving non-conceptual perceptual representations. This more restricted usage has faded, and the term of “cognition” is now frequently applied even to early vision.⁸

Other theoretical differences arise in considering situated cognition. As amply illustrated in this volume, the embodied cognition camp assigns the body a significant role in cognitive achievements. They sometimes claim to replace the machinery of representations with non-representational dynamic processing. That the structure of the body is important in the cycle of

perception and action would not be denied by a theorist such as Neisser (1976). But he weds the outlook with information-processing accounts. Those who do otherwise (non-representationalists) cannot be arguing simply from the fact of embodiment; rather, they must give other reasons for rejecting representations. The extended cognition thesis also comes in representationalist (e.g. Clark and Chalmers, 1998) and non-representationalist forms (discussed in Wheeler, 2005; see Chemero, 2009). Again, the extended cognition hypothesis, according to which the world itself can enter into cognitive processes that guide effective behavior, is not intrinsically non-representational. The need for representations surely hinges on whether, in order to explain intelligent (adaptive, appropriate, flexible) behavior in its many manifestations, representations bring explanatory advantages some or all of the time (see also Shapiro, 2011, ch. 5).⁹

Anti-Cartesian cognitive science

In the literature of cognitive science, there is much talk of rejecting a Cartesian picture of the mind in favor of some other view, representationalist or not. This can mean many things, including rejecting Cartesian dualism (Bechtel *et al.*, 1998, p. 62), or rejecting the view that rational manipulation of internal representations, ignoring body and environment, suffices for effective behavior (Rowlands, 1999, pp. 4–5; van Gelder, 1995, pp. 380–81). For the most part, anti-Cartesians avoid engaging Descartes' own writings. Wheeler (2005) is an exception. He engages Descartes directly. Because this proponent of extended cognition considered it important to show that Descartes held the to-be-rejected views, correcting this mistaken impression is worthwhile. Leaving substance dualism aside and focusing on intelligent or situationally appropriate behavior, I present Descartes as an advocate of embodied behavioral effectiveness and extended memory.

Wheeler (2005, chs. 2–3) seeks to establish that Descartes subscribed to five theses that form part of a contemporary “Cartesian psychology.” The five are: (1) mind is representational, (2) intelligent action occurs through sense-represent-plan-move cycles, (3) perception is essentially inferential, (4) most intelligent human action comes from general-purpose reasoning mechanisms, and (5) the environment provides only problems, sensory inputs, and a stage for pre-planned actions (Wheeler, 2005, ch. 3). Here, I challenge (2)–(5).

There is no doubt that Descartes held that mind is representational. Further, he would contend that true intelligence is mental. But he denied that all situationally appropriate behavior arises from the mind and that the mind simply uses the body to carry out actions. On the contrary, he held that many behaviors result from physiological processes: “a very large number of the motions occurring in us do not depend on mind,” including “actions such as walking, singing, and the like, when these occur without the mind attending to them” (Descartes, 1984, p. 161). Bodily mechanisms are attuned to environmental circumstances: “When people take a fall, and stick out their hands so as to protect their head, it is not reason that instructs them to do this; it is simply that the sight of the impending fall reaches the brain and sends the animal spirits into the nerves in the manner necessary to produce this movement even without any volition” (*ibid.*).¹⁰ Descartes advanced a theory of the passions or emotions according to which, at the sight of a frightful animal, brain processes alone cause the body to turn and flee. These same processes simultaneously cause the feeling of fear. The function of this feeling is “to encourage the soul to want to flee”; the passions more generally have the function of “disposing the soul to want the things” that the body is already engaged in (Descartes, 1985, p. 343). Note that there is no “sense-represent-plan-move cycle” here. Rather, there is: bodily process, which causes movement and an emotion that inclines the soul or mind (without rational deliberation or “general reasoning”) to want to carry on the movement (see Hatfield, 2007). In these cases,

the behavioral agent (i.e. the human subject) is not the mind alone, but the body plus mind, and the mind's function need not be deliberative.

Descartes did not regard all perception as inferential; he developed a sophisticated physiological model of distance perception, according to which an experience of distance is directly caused in the mind by brain mechanisms (see Hatfield, 1992, pp. 356–57).¹¹ Perhaps the most surprising passage to cite here concerns embodied and extended memory. In a letter explaining his views on memory, Descartes of course affirms that the brain is involved in memory. But so is the body: “I think that all the nerves and muscles can be so utilized [for memory], so that a lute player, for instance, has a part of his memory in his hands” (Descartes, 1991, p. 146). And there is “extended” memory: “what people call ‘local memory’ is outside us: for instance, when we have read a book, not all the impressions which can remind us of its contents are in our brain. Many of them are on the paper of the copy which we have read” (ibid.). Presumably, some of the book's content enters brain memory; the printed pages constitute a more extensive memory record. Descartes does not hold that the page is part of the mind, but it is part of the phenomenon of memory.

One could pile on examples to show how Cartesian psychology and theory of mind has been caricatured in recent times, abetting a deep postmodern animosity toward Descartes.¹² That is not the present point. Rather, we should believe that this version of Cartesian psychology as targeted by adherents of situated cognition was invented for a reason, to portray an opponent. But, leaving substance dualism aside, the real opponent is not Descartes. So what is it?

Conclusion: the real target? And whence now?

The real target of many of those who emphasize situatedness and environmental embedding is the classical symbolist conception, or that together with those connectionist models that eschew environmental relations. The static “rules and representations” that are usually the target of rebellion are explicitly represented rules conjoined with symbolic representations.¹³ A fine target. But there have been alternatives to that paradigm all along. An attack that merely shows that some behaviors are successfully modeled without invoking symbolic computation is not news. Effort should instead be spent in articulating what the alternative frameworks are actually saying.

Concerning representation, we have met two alternative frameworks. One allows representations to vary continuously and one seeks to avoid representations altogether. A third variant uses representations sometimes but not others (e.g. Wheeler, 2005). All three seek to include the body and the environment.

The non-representationalist frameworks may explain behaviors such as toddler walking and perseverative reaching behavior in infants (Smith and Thelen, 2003). Dyed-in-the-wool symbolists would model these behaviors symbolically. But others, including Descartes, might explain them through non-mentalistic physiological processes. Other behaviors, such as tracking and catching prey, or using a mass transit system, may invite other sorts of modeling, perhaps requiring or at least inviting internal representations.

Let us accept Wheeler's (2005) plea that cognitive psychology and cognitive science, construed broadly, should aim to explain a wide range of intelligent (adaptive, appropriate, flexible) behaviors. If intelligent behavior, broadly construed, is the object of explanation – perhaps augmented by human perceptual and other types of experience¹⁴ – then there needs to be consideration of the varieties of behavior (and experiences). This may lead to the notion of a variety of intelligences.

Evolution is frequently omitted from situated discussion (but see Gibson, 1966, ch. 9; Rowlands, 1999, chs. 4, 11; Wilson, 2004).¹⁵ The literature on the evolution of mind might

help in thinking about the varieties of behavior and intelligence. In the evolution of the hominid line, group hunting, tool making, and habitat improvement arose at various points. What cognitive mechanisms allowed for these behaviors to arise? Some theorists posit the evolution of several different types of modular intelligence (e.g. Mithen, 1996, 2013). Others emphasize a smaller set of adaptations, perhaps starting from auto-cued motor sequences used for making tools and then for dancing (e.g. Donald, 1991, 2013). Even if not all actions are planned, skilled action may involve representational routines to guide its manifestation. Engaging in helping behavior may require intention-reading (Warneken, 2013). Other animals show other ranges of skills, requiring specific types of competencies (e.g. Seyfarth and Cheney, 2013).

There is no such thing as intelligent behavior in general. What may be needed now is a survey of behavioral and cognitive skills and other tendencies, with an eye toward the explanatory resources that can account for them. Representations, including non-conceptual and conceptual, action-guiding and recognitional, individual and intention-sharing or cooperation-affording, are sure to be in the mix. They need not be symbolic or come formulated in explicit rules. Connectionist and dynamical systems may use them. They may vary continuously or be discrete. But they are here to stay.

Notes

- 1 For a complementary account of the renewal of cognitive approaches, which discusses yet other portrayals, see Hatfield, 2002. See also Bechtel, Abrahamsen, and Graham, 1998.
- 2 The “assignment” of intentional content is not merely instrumental but imputes “original intentionality” to the system (Haugeland, 1981, p. 33). Haugeland specifies that such assignments must make sense of the agent’s behavior “relative to the environment.” While the conditions on an adding machine are simple formal truth, in assigning content to behaving organisms “other conditions” are important, including context, that is, considering outputs “in relation to one another and in relation to the situation in which they are produced” (pp. 32–33). Fodor (1975, ch. 2, esp. pp. 71–73) also recognizes environmental constraints in interpreting propositional attitudes (hence internal formulae), but less clearly or forcefully so. Only subsequently did Fodor (1980) propose that cognitive science should be concerned only with the formal operations mediating between input and output and not relations to the environment. Methodological solipsism (or so-called “narrow content”) was not a founding or essential feature of symbolic computationalism. On the contrast between behavior narrowly construed and the objects of investigation in mainstream cognitive psychology of the 1970s and 1980s, see Shapiro, 1994. Shapiro shows that many discussions in philosophy of psychology treated behavior as mere physically described movement, by contrast with environmentally related descriptions of behavior by ethologists, behaviorists, and cognitive psychologists.
- 3 On the interpretation of Marr’s theory in debates over wide and narrow content, see Shapiro, 1993.
- 4 On affinities between connectionism with a dynamical systems approach and the field theories of Gestalt psychology, see Hatfield and Epstein, 1985, pp. 179–83.
- 5 Adherents of dynamical systems approaches sometimes acknowledge an affinity with Gestalt field theories (e.g. Kelso, 1995). On Gestalt dynamical theory, see Hatfield and Epstein, 1985, pp. 179–83, and Epstein and Hatfield, 1994, pp. 175–77.
- 6 Other, broader specifications of cognitive science, which define it as “a cross-disciplinary enterprise devoted to exploring and understanding the nature of the mind” (Frankish and Ramsey, 2012, p. 1), apparently equate *mind* with *cognition*, either unacceptably narrowing the former term or expanding the latter.
- 7 There have been attempts to specify a “mark of the cognitive.” Adams and Aizawa (2008) propose that part of the mark is underived content, belonging to a system intrinsically. This accords with my notion of mentalistic representation and mental content. Perceptual and cognitive psychologists normally assume underived content. To this, Adams and Aizawa (2008, ch. 4) add that, for a system to be cognitive, certain sorts of processes must take place, which they indicate through example. Rowlands (2010, pp. 110–11) offers a criterion involving information processing and representations that belong

- to subjects (in support of extended perception and cognition). In a different spirit, some (see Thompson 2007, pp. 122–27) extend the “cognitive” to include all effective activities for self-maintenance in relation to the environment (so that every living thing on Earth is cognitive).
- 8 It may still be useful to distinguish non-conceptual perceptual processes from conceptual ones. One might even consider non-conceptual perceptual content, of which size and shape at a distance are typical instances (Dretske, 1981, ch. 6), to be “cognitive” in that they stably represent the spatial environment (the latter is not Dretske’s usage). Such usage would prize apart the conceptual and the cognitive. (Thanks to Louise Daoust for this suggestion.)
 - 9 Wilson (2004) renders individuals as the bearers of *psychological* states but regards *cognitive* states as locationally wide (extending into the environment) and treats Gibsonian optical arrays as parts of locationally wide computational systems (Wilson, 2004, ch. 7, esp. p. 171). His distinction between psychological and cognitive states needs fuller articulation, as does the sense in which the optic array is cognitive (as opposed to being an environmental condition that sensory systems exploit, including those deemed to engage in information processing).
 - 10 “Animal spirits” are purely material processes that serve neural functions in Descartes’ scheme.
 - 11 Descartes also described mechanisms for size and distance perception involving inference (Hatfield, 1992, pp. 351–56).
 - 12 The caricatures often arise from reading Descartes’ *Meditations* as if every statement, including those made under radical doubt, should be taken at face value (see Fodor, 1980, pp. 64–65). When Descartes speaks of being only a mind, he is taken literally, despite his subsequent conclusion that the human being consists of mind and body (1984, pp. 24, 61). His skepticism toward the senses is allowed to stand, despite his reconception of sensory function as embodied; the primary function of the senses is bodily preservation in relation to environmental circumstances (Descartes, 1984, pp. 56–61).
 - 13 An even smaller target, frequently invoked, is the subclass of classical (symbolist) models espousing methodological solipsism or narrow content. Fodor (1980) advanced methodological solipsism in despair of fixing representational content by environmental relations: accordingly, cognitive science should study only internal symbolic computations. Stich (1983) embraced the despair; under renewed Gibsonian inspiration, few would now.
 - 14 Human perceptual experience and other forms of consciousness are included in contemporary research, both as objects of explanation and sources of data. Phenomenal experience certainly is included in vision science (Palmer, 1999). The situated cognition literature is mixed anent its interest in such data.
 - 15 Among environmentally attuned representationalist views, evolutionary considerations have been invoked in teleosemantics, e.g. Dretske, 1986.

References

- Adams, F., and Aizawa, K. (2008). *The bounds of cognition*. Malden, MA: Blackwell.
- Allen, R., and Reber, A. S. (1998). Unconscious intelligence. In W. Bechtel and G. Graham (Eds.), *Companion to cognitive science* (pp. 314–23). Malden, MA: Blackwell.
- Baars, B. J. (1985). *The cognitive revolution in psychology*. New York: Guilford.
- Bartlett, F. C. (1932). *Remembering: A study in experimental and social psychology*. Cambridge: Cambridge University Press.
- (1958). *Thinking: An experimental and social study*. New York: Basic Books.
- Bechtel, W., and Abrahamsen, A. (1991). *Connectionism and the mind: An introduction to parallel processing in networks*. Oxford: Basil Blackwell.
- Bechtel, W., Abrahamsen, A., and Graham, G. (1998). The life of cognitive science. In W. Bechtel and G. Graham (Eds.), *Companion to cognitive science* (pp. 1–104). Malden, MA: Blackwell.
- Bechtel, W., and Graham, G. (Eds.) (1998). *A companion to cognitive science*. Malden, MA: Blackwell.
- Broadbent, D. E. (1958). *Perception and communication*. New York: Pergamon Press.
- Bruner, J. S., Goodnow, J. J., and Austin, G. A. (1956). *A study of thinking*. New York: Wiley.
- Chemero, A. (2009). *Radical embodied cognitive science*. Cambridge, MA: MIT Press.
- Clark, A. (2010). Coupling, constitution, and the cognitive kind: A reply to Adams and Aizawa. In Richard Menary (Ed.), *The extended mind* (pp. 81–99). Cambridge, MA: MIT Press.
- Clark, A., and Chalmers, D. (1998). The extended mind. *Analysis*, 58, 7–19.
- Collins, A. (1977). Why cognitive science. *Cognitive Science*, 1, 1–2.
- Dawson, M. R. W. (1998). *Understanding cognitive science*. Malden, MA: Blackwell.

- Descartes, R. (1984). *Philosophical writings of Descartes*: Vol. 2 (J. Cottingham, R. Stoothoff, and D. Murdoch, Trans.). Cambridge: Cambridge University Press.
- (1985). *Philosophical writings of Descartes*: Vol. 1 (J. Cottingham, R. Stoothoff, and D. Murdoch, Trans.). Cambridge: Cambridge University Press.
- (1991). *Philosophical writings of Descartes*: Vol. 3. *Correspondence* (J. Cottingham, R. Stoothoff, D. Murdoch, and A. Kenny, Trans.). Cambridge: Cambridge University Press.
- Donald, M. (1991). *Origins of the modern mind*. Cambridge, MA: Harvard University Press.
- (2013). Mimesis theory re-examined, twenty years after the fact. In G. Hatfield and H. Pittman (Eds.), *Evolution of mind, brain, and culture* (pp. 169–92). Philadelphia, PA: University of Pennsylvania Museum of Anthropology and Archaeology.
- Dretske, F. (1981). *Knowledge and the flow of information*. Cambridge, MA: MIT Press.
- (1986). Misrepresentation. In R. J. Bogdan (Ed.), *Belief: Form, content, and function* (pp. 17–36). Oxford: Oxford University Press.
- Epstein, W. (1973). The process of “taking into account” in visual perception. *Perception*, 11, 75–83.
- Epstein, W., and Hatfield, G. (1994). Gestalt psychology and the philosophy of mind. *Philosophical Psychology*, 7, 163–81.
- Eysenck, M. W., and Keane, M. T. (2000). *Cognitive psychology: A student’s handbook* (4th ed.). Hove, East Sussex: Psychology Press.
- Fodor, J. A. (1975). *Language of thought*. New York: Crowell.
- (1980). Methodological solipsism considered as a research strategy in cognitive psychology. *Behavioral and Brain Sciences*, 3, 63–109.
- Frankish, K., and Ramsey, W. M. (2012). Introduction. In K. Frankish and W. M. Ramsey (Eds.), *The Cambridge handbook of cognitive science* (pp. 1–6). Cambridge: Cambridge University Press.
- Gibson, J. J. (1950). *The perception of the visual world*. Boston: Houghton Mifflin.
- (1966). *The senses considered as perceptual systems*. Boston: Houghton Mifflin.
- (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.
- Hatfield, G. (1988). Representation and content in some (actual) theories of perception. *Studies in History and Philosophy of Science*, 19, 175–214.
- (1990). Gibsonian representations and connectionist symbol-processing: Prospects for unification. *Psychological Research*, 52, 243–52.
- (1991a). Representation and rule-instantiation in connectionist systems. In T. Horgan and J. Tienson (Eds.), *Connectionism and the philosophy of mind* (pp. 90–112). Boston: Kluwer.
- (1991b). Representation in perception and cognition: Connectionist affordances. In W. Ramsey, D. E. Rumelhart, and S. P. Stich (Eds.), *Philosophy and connectionist theory* (pp. 163–95). Hillsdale, NJ: Erlbaum.
- (1992). Descartes’ physiology and its relation to his psychology. In J. Cottingham (Ed.), *Cambridge companion to Descartes* (pp. 335–70). Cambridge: Cambridge University Press.
- (2002). Psychology, philosophy, and cognitive science: Reflections on the history and philosophy of experimental psychology. *Mind and Language*, 17, 207–32.
- (2003). Behaviourism and psychology. In T. Baldwin (Ed.), *Cambridge history of philosophy, 1870–1945* (pp. 640–48). Cambridge: Cambridge University Press.
- (2007). The *Passions of the Soul* and Descartes’s machine psychology. *Studies in History and Philosophy of Science*, 38, 1–35.
- Hatfield, G., and Epstein, W. (1985). The status of the minimum principle in the theoretical analysis of vision. *Psychological Bulletin*, 97, 155–86.
- Hatfield, G., and Pittman, H. (Eds.) (2013). *Evolution of mind, brain, and culture*. Philadelphia, PA: University of Pennsylvania Museum of Anthropology and Archaeology.
- Haugeland, J. (1978). The nature and plausibility of cognitivism. *Behavioral and Brain Sciences*, 1, 215–26.
- (1981). Semantic engines: An introduction to mind design. In J. Haugeland (Ed.), *Mind design* (pp. 1–34). Cambridge, MA: MIT Press.
- Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of brain and behavior*. Cambridge, MA: MIT Press.
- Kosslyn, S. M., and Hatfield, G. (1984). Representation without symbol systems. *Social Research*, 51, 1019–45.
- Lindsay, P. H., and Norman, D. A. (1972). *Human information processing: An introduction to psychology*. New York: Academic Press.
- Marr, D. (1982). *Vision: Computational investigation into the human representation and processing of visual information*. San Francisco: Freeman.

- Massaro, D. W. (1989). *Experimental psychology: An information processing approach*. San Diego: Harcourt Brace Jovanovich.
- Mithen, S. (1996). *The prehistory of the mind: A search for the origin of art, science and religion*. London: Thames & Hudson.
- (2013). The cathedral model for the evolution of human cognition. In G. Hatfield and H. Pittman (Eds.), *Evolution of mind, brain, and culture* (pp. 217–33). Philadelphia, PA: University of Pennsylvania Museum of Anthropology and Archaeology.
- Neisser, U. (1967). *Cognitive psychology*. New York: Appleton-Century-Crofts.
- (1976). *Cognition and reality: Principles and implications of cognitive psychology*. San Francisco: Freeman.
- Newell, A., Shaw, J. C., and Simon, H. A. (1958). Elements of a theory of human problem solving. *Psychological Review*, 65, 151–66.
- Palmer, S. E. (1999). *Vision science: Photons to phenomenology*. Cambridge, MA: MIT Press.
- Rock, I. (1975). *Introduction to perception*. New York: Macmillan.
- (1983). *The logic of perception*. Cambridge, MA: MIT Press.
- Rowlands, M. (1999). *The body in mind: Understanding cognitive processes*. Cambridge: Cambridge University Press.
- (2010). *The new science of the mind: From extended mind to embodied phenomenology*. Cambridge, MA: MIT Press.
- Ryle, G. (1949). *The concept of mind*. London: Hutchinson.
- Seyfarth, R. M., and Cheney, D. L. (2013). The primate mind before tools, language, and culture. In G. Hatfield and H. Pittman (Eds.), *Evolution of mind, brain, and culture* (pp. 105–21). Philadelphia, PA: University of Pennsylvania Museum of Anthropology and Archaeology.
- Shapiro, L. (1993). Content, kinds, and individualism in Marr’s theory of vision. *Philosophical Review*, 102, 489–513.
- (1994). Behavior, ISO functionalism, and psychology. *Studies in History and Philosophy of Science*, 25, 191–209.
- (2011). *Embodied cognition*. London: Routledge.
- Smith, L. B., and Thelen, E. (2003). Development as a dynamic system. *Trends in Cognitive Sciences*, 7, 343–48.
- Smolensky, P. (1988). On the proper treatment of connectionism. *Behavioral and Brain Sciences*, 11, 1–74.
- Spelke, E. S. (1988). Where perceiving ends and thinking begins: The apprehension of objects in infancy. In A. Yonas (Ed.), *Perceptual development in infancy* (pp. 197–234). Hillsdale: Erlbaum.
- Stich, S. (1983). *From folk psychology to cognitive science: The case against belief*. Cambridge, MA: MIT Press.
- Thompson, E. (2007). *Mind in life: Biology, phenomenology, and the sciences of mind*. Cambridge, MA: Harvard University Press.
- Turvey, M. T., and Carello, C. (1981). Cognition: The view from ecological realism. *Cognition*, 10, 313–21.
- (1995). Some dynamical themes in perception and action. In R. F. Port and T. van Gelder (Eds.), *Mind as motion: Explorations in the dynamics of cognition* (pp. 373–401). Cambridge, MA: MIT Press.
- van Gelder, T. (1995). What might cognition be, if not computation? *Journal of Philosophy*, 92, 345–81.
- van Gelder, T., and Port, R. F. (1995). It’s about time: An overview of the dynamical approach to cognition. In R. F. Port and T. van Gelder (Eds.), *Mind as motion: Explorations in the dynamics of cognition* (pp. 1–43). Cambridge, MA: MIT Press.
- Warneken, F. (2013). The origins of human cooperation from a developmental and comparative perspective. In G. Hatfield and H. Pittman (Eds.), *Evolution of mind, brain, and culture* (pp. 149–68). Philadelphia, PA: University of Pennsylvania Museum of Anthropology and Archaeology.
- Wheeler, M. (2005). *Reconstructing the cognitive world: The next step*. Cambridge, MA: MIT Press.
- Wilson, R. A. (2004). *Boundaries of the mind: The individual in the fragile sciences*. Cambridge: Cambridge University Press.

REVOLUTION, REFORM, OR BUSINESS AS USUAL?

The future prospects for embodied cognition

Michael Wheeler

A pre-revolutionary situation?

When all the data and arguments are in, will the recent flurry of work in embodied cognition deliver a revolutionary paradigm shift in the sciences and philosophy of mind? Or will it be a case of business as usual in the mind-targeting laboratories and armchairs around the globe? Or is the most likely outcome a reformist tweak in which embodied cognition research is recognized as making genuine and important methodological or orienting contributions to cognitive science, while leaving the most fundamental conceptual foundations of the field intact – as Rupert nicely puts it in his sobering set of conclusions regarding the revolutionary implications of embodied approaches in general, “more of a nudging than a coup” (Rupert, 2009, p. 242)?

Reaching a judgment on this issue is trickier than it may at first appear, since it is not simply a matter of working out whether or not some homogeneous and well-delineated new research program in cognitive science has succeeded, or will succeed, in substantively reforming, or even deposing, the orthodox view in the field. (For present purposes, the orthodox view may be located by its adherence to the principle that intelligent thought and action are standardly to be explained in terms of the building and manipulation of inner representational states by inner computational processes.) Indeed, if we consider the assortment of thinkers who congregate under the banner of embodied cognition, and we reflect on the range of theoretical approaches on offer, it turns out that they constitute a far from univocal crowd. Because of this, my goal in this chapter is not to pronounce on the future prospects for embodied cognition research *in general* – that would require at least one book – but rather to evaluate the prospects for a limited number of specific but prominent views that march under that banner. In each case I shall endeavor to get clear about the fundamental theoretical commitments of the view in relation to a specific diagnostic issue, namely what its advocates mean by the presumably foundational notion of being “embodied.”

The implementational body

According to the hypothesis of *extended cognition* (ExC), there are actual (in this world) cases of intelligent thought and action in which the thinking and thoughts (more precisely, the material

vehicles that realize the thinking and thoughts) are spatially distributed over brain, body and world, in such a way that the external (beyond-the-skull-and-skin) factors concerned are rightly accorded cognitive status.¹ To bring ExC into proper view, it is useful to compare it with an adjacent position in intellectual space, namely the hypothesis of *embedded cognition*. According to this second and arguably less radical position, intelligent thought and action are regularly, and perhaps sometimes necessarily, causally dependent on the bodily exploitation of certain external props or scaffolds.² So, consider the example of a mathematical calculation achieved, in part, through the bodily manipulation of pen and paper. For both the embedded view and ExC, what we have here is a brain-body-pen-and-paper system involving a beyond-the-skin element that, perhaps among other things, helps to transform a difficult cognitive problem into a set of simpler ones (e.g. by acting as storage for intermediate calculations). For the embedded theorist, however, even if it is true that the overall mathematical problem could not have been solved, at least by some particular mathematician, without the use of pen and paper, nevertheless the external resource in play retains the status of a non-cognitive aid to some internally located thinking system. It certainly does not qualify as a proper part of the cognitive architecture itself. In other words, the thinking in evidence remains a resolutely inner, paradigmatically neural, phenomenon, although one that has been given a performance boost by its local technological ecology. By contrast, for the advocate of ExC, the coupled system of pen-and-paper resource, appropriate bodily manipulations, and in-the-head processing *may* itself count as a cognitive architecture, even though it is a dynamically assembled (rather than hard-wired) and essentially temporary (rather than persisting) coalition of elements. In other words, each of the differently located components of this distributed (over brain, body and world) multifactor system enjoys cognitive status, where the term “cognitive status” should be understood as indicating whatever status it is that we ordinarily grant the brain in mainstream cognitive science. Another way to put this is to say that, according to the embedded view, the dependence of cognition on environmental factors is “merely” causal, whereas, according to ExC, that dependence is constitutive (Adams and Aizawa, 2008).

ExC naturally qualifies as a species of embodied cognition, because it takes non-neural bodily factors (e.g. manipulative movements of the body) to be parts of the realizing substrate of cognitive phenomena. Given our present remit, however, it is instructive to bring out the precise nature of the style of embodiment that is on offer. Here is an orienting thought. Surprisingly, perhaps, the possibility of extended cognition is a straightforward consequence of what still deserves to be labeled the house philosophy of mind in cognitive science, namely *functionalism*. The cognitive-scientific functionalist holds that what makes a state or process cognitive is not its material composition, but the functional role it plays in generating psychological phenomena, by intervening causally between systemic inputs, systemic outputs and other functionally identified, intrasystemic states and processes. Computational explanations, as pursued in, say, cognitive psychology and artificial intelligence (AI), are functionalist in this sense. Of course, historically, the assumption in cognitive science has been that the organized collection of states and processes that the functionalist takes to be the machinery of mind will be realized by the nervous system (or, in hypothetical cases of minded robots or aliens, whatever the counterpart of the nervous system inside the bodily boundaries of those cognitive agents turns out to be). In truth, however, there isn’t anything in the letter of functionalism that mandates this internalism (Wheeler, 2010a, 2010b). After all, what functionalism demands is that we specify the causal relations that exist between some target element and a certain set of systemic inputs, systemic outputs and other functionally identified, intrasystemic elements. Nothing here demands internalism, since the boundaries of the functionally identified system of interest – i.e. the cognitive system – may in principle fall beyond boundaries of the organic sensorimotor interface.

Clark (2008a, 2008b; followed by Wheeler 2010a, 2010b, 2011a) uses the term *extended functionalism* to describe the combination of functionalism and ExC. This moniker is useful, as long as one remembers that the qualification “extended” attaches to the nature of cognition and not to the thesis of functionalism. Nothing about that venerable philosophical thesis has changed, since the claim that cognition might be extended merely unpacks one implication of the functionalist picture that had been there all along. As one might put it, ExC, if true, is simply a footnote to functionalism. If we look at things from the other direction, however, the alliance with functionalism gives the ExC theorist something she needs – assuming, that is, that she wants to hold onto the presumably attractive thought that the very same type-identified cognitive process may, on some occasions, take place wholly inside the head, while on others it may take place in an extended brain-body-environment system. To explain: even if some mathematical calculations are simply too difficult for me to complete entirely in my brain, there are others for which it seems plausible to say that, although on Monday I may carry them out using pen and paper, on Thursday I may call only on my organic resources. Now, if we are to describe these alternative problem-solving routines as two realizations of the very same mathematical cognition, it must be possible for the very same psychological reasoning process to enjoy (at least) two different material instantiations. In other words, the target cognitive phenomenon must be *multiply realizable*. And while functionalism may not be necessary for multiple realizability, it is standardly thought to be sufficient, since a function is something that enjoys a particular kind of independence from its implementing material substrate. Indeed, it seems plausible that anything worthy of being a function must, in principle, be multiply realizable.³

Functionalism makes extended cognition a conceptual possibility, but it doesn’t make ExC true. What is needed, additionally, is an account of which functional contributions count as cognitive contributions and which don’t. After all, as the critics of ExC have often observed, there undoubtedly will be functional differences between a distributed system and a purely inner system that allegedly realize the same cognitive process. For example, our brain-body-pen-and-paper mathematical system involves visual access to, and the bodily manipulation of, the material symbols on the page. *At some level of functional description*, there will be aspects of these processes that have no counterparts in the purely inner case (e.g. the functions involved in controlling visual gaze). So we will need to know which, if any, of the functional differences in evidence are relevant to determining the cognitive (or otherwise) status of the external elements. In other words, we need to provide a *mark of the cognitive* (Adams and Aizawa, 2008), a scientifically informed account of what it is to be a proper part of a cognitive system that, so as not to beg any questions, is independent of where any candidate element happens to be spatially located (Wheeler, 2010a, 2010b, 2011a, 2011b). The idea is that once a mark of the cognitive is specified, further philosophical and empirical legwork will be required to find out where cognition (so conceived) falls – in the brain, in the non-neural body, in the environment, or, as ExC predicts will sometimes be the case, in a system that extends across all of these aspects of the world.

To see how this might work, let’s consider a candidate for a functionalist-friendly mark of the cognitive (Wheeler, 2011a). Newell and Simon famously claimed that a suitably organized “physical symbol system has the necessary and sufficient means for general intelligent action” (Newell and Simon, 1976, p. 116). A physical symbol system (henceforth PSS) is (roughly) a classical computational system instantiated in the physical world, where a classical computational system is (roughly) a system in which atomic symbols are combined and manipulated by structure-sensitive processes in accordance with a language-like combinatorial syntax and semantics. Although Newell and Simon adopted what we might call an unrestricted form of the claim that

cognition (which I am taking to be equivalent to “the necessary and sufficient means for general intelligent action”) is a matter of classical symbol manipulation, one might reasonably restrict the claim to a narrower range of phenomena, perhaps most obviously to “high-end” achievements such as linguistic behavior, natural deduction and mathematical reasoning. And although classical cognitive scientists in general thought of the symbol systems in question here as being realized inside the head, there is nothing in the basic concept of a PSS that rules out the possibility of extended material implementations (cf. the traditional move of bolting internalism onto functionalism). What this line of reasoning gives us, then, is the claim that “being a suitably organized PSS” is one mark of the cognitive.

So what? Bechtel (1996) defends the view that cognitive achievements such as mathematical reasoning, natural-language processing and natural deduction are (at least sometimes) the result of sensorimotor-mediated interactions between internal connectionist networks and external symbol systems, where the latter (but not the former) feature various forms of combinatorial syntax and semantics. So in these cases the combinatorial structure that, if our mark of the cognitive is correct, is indicative of cognition, resides not in our internal processing engine, but rather in public systems of external representations (e.g. written or spoken language, mathematical notations). The capacity of connectionist networks to recognize and generalize from patterns in bodies of training data (e.g. large numbers of correct derivations in sentential arguments), plus the temporal constraints that characterize real embodied engagements with stretches of external symbol structures (e.g. different parts of the input will be available to the network at different times, due to the restrictions imposed by temporal processing windows) are then harnessed to allow those networks to be appropriately sensitive to the constraints of an external compositional syntax. One might be tempted to conclude from this that a Bechtel-style network-plus-symbol-system architecture is an extended PSS. Of course, more would need to be said before we should give in wholeheartedly to this temptation (Wheeler, 2011a). However, let’s assume that any concerns can be addressed. If the further thought that I have flirted with is correct, and being a suitably organized PSS is a mark of the cognitive, then, by virtue of being an extended PSS, the Bechtel architecture is also an extended cognitive system.

There are, then, reasons to think that extended functionalism may deliver ExC. And if extended functionalism is a form of embodied cognition, then the future prospects for embodied cognition are correspondingly rosy. But however revolutionary a result extended functionalism may mandate in relation to where cognition is to be found, the fact is that that outcome neither signals a fundamental change in our understanding of the relationship between cognition and material embodiment, nor (relatedly, as we shall see in a moment) forces us in the direction of a radically new theoretical language in which to carry out cognitive science.

On the first point, consider that, for the functionalist, *and thus for the extended functionalist*, the physical body is relevant “only” as an explanation of how cognitive states and processes are implemented in the material world. Indeed, since multiple realizability, as established by functionalism, requires that a single type of cognitive state or process may enjoy a range of different material instantiations, there is no conceptual room for the specific material embodiment of a particular instantiation to be an essential feature of mind. (Although it may be true that some functions can, as a matter of empirical fact, be implemented only in certain kinds of extant material system, that would be no more than a practical constraint.) So, despite the fact that, along one dimension (see above), extended functionalism is a fully paid-up member of the embodied cognition fraternity, there is another, arguably more fundamental, dimension along which the view emerges as having a peculiarly disembodied character. (Here one is reminded of Searle’s observation that functionalism, although standardly depicted as a materialist theory of

mind, is fully consistent with substance dualism [Searle, 1980].) This leads us to our second point. In observing that functionalism is the house philosophy of mind in orthodox cognitive science, one thereby highlights the close theoretical connection that obtains between functionalism and representational-computational models of mind. Indeed, the traditional account of the relation between a computational virtual machine and the range of physical machines in which that virtual machine may be instantiated is a particular version of the implementation relation that characterizes functionalist multiple realizability, while the notion of a computational system, via research in AI and computational cognitive psychology, provides a concrete and scientifically productive technological realization of the functionalist schema. It is unsurprising, then, that extended functionalism is routinely pursued in a computational register. Indeed, arguably the most common proposal for an extended cognitive system involves external representational elements that are taken to be constitutive components of the cognitive architecture in question precisely because of the way in which they are poised to contribute to the (distributed) implementation of an information-processing solution to some cognitive problem. Here one might mention the canonical example of the linguistic inscriptions in Otto's notebook that allegedly realize the content of his extended dispositional beliefs (Clark and Chalmers, 1998), but the case above of an extended PSS is an example of the very same signature.

If all this is right, then although extended functionalism, through its rejection of neurocentric internalism, may in some ways advance the embodied cause, it nonetheless leaves the conventional explanatory language of cognitive science fully intact. By analogy with Russian history, this is 1905, not 1917.

The vital body

Alan Turing once remarked that, “[i]n the nervous system chemical phenomena are at least as important as electrical” (Turing, 1950, p. 46). This is a striking comment, especially when one recognizes that, even in the connectionist regions of cognitive science, where the abstract physical organization of the brain, depicted as a distributed network of simple processing units, inspires the abstract structure of the cognitive architecture on offer, neural processes are treated as essentially a matter of electrical signals transmitted along wires. Connectionist networks are, of course, standardly interpreted as computational (and thus as representational) systems, even though they often need to be analyzed in terms of cognitive functions specified at a finer level of grain than those performed by classical computational systems (e.g. using mathematical relations between units that do not respect the boundaries of linguistic or conceptual thought). In the present context, the importance of this interpretation of connectionism is captured by Clark's (1989) philosophical gloss on the field as advocating a “microfunctionalist” account of cognition. As we have seen, functionalism demands an implementational notion of embodiment, a fact that surely remains unaffected by the “micro” nature of the functional grain appropriate to connectionist theorizing. Tying these thoughts together, one might speculate that the conceptualization of the brain as an electrical signaling system – a conceptualization that depends, in part, on abstracting away from the chemical dynamics of the brain – plausibly contributes positively to whatever cogency the computationalist-microfunctionalist picture has. So what happens when the chemical dynamics of brains are brought into view? Does this herald the arrival of a radical notion of embodiment, and thus of embodied cognition, one that brings revolution to the door?

To focus on a concrete example, consider reaction-diffusion (RD) systems. These are distributed chemical mechanisms involving constituents that are (a) transformed into each other by local chemical reactions and (b) spread out in space by diffusion. RD systems plausibly explain

the kind of behavior in some unicellular organisms (e.g. slime molds) that researchers in the field of artificial life describe as minimally cognitive, behavior such as distinguishing between different relevant environmental factors, adapting to environmental change, and organizing collective behavior. Many of the molecular pathways present in unicellular organisms have been conserved by evolution to play important roles in animal brains, so an understanding of the ways in which RD systems may generate minimally cognitive behavior will plausibly help us to explain the mechanisms underlying higher-level natural cognition. Against this background, Dale and Husbands (2010) show that a simulated RD system (conceived as a one-dimensional ring of cells within which the concentration of two coupled chemicals changes according to differential equations governing within-cell reactions and between-cell diffusion) is capable of intervening between sensory input (from whiskers) and motor output (wheeled locomotion) to enable a situated robot to achieve the following minimally cognitive behaviors: (i) tracking a falling circle (thus demonstrating orientation); (ii) fixating on a circle as opposed to a diamond (thus demonstrating discrimination); (iii) switching from circle fixation behavior to circle avoidance behavior on the presentation of a particular stimulus (thus demonstrating memory).

To see why this result might be thought to have insurrectionary implications, let's introduce Collins's notion of *embrained knowledge*. According to Collins, knowledge is embrained just when "cognitive abilities have to do with the physical setup of the brain," where the term "physical setup" signals not merely the "way neurons are interconnected," but also factors to do with "the brain as a piece of chemistry or a collection of solid shapes" (Collins, 2000, p. 182). When deployed to generate minimally cognitive behavior, RD systems, characterized as they are by the exploitation of spatio-temporal chemical dynamics, plausibly instantiate such embrained knowledge. But what does this tell us? At first sight it might seem that embrained knowledge must fail to reward any functionalist (or microfunctionalist) gloss. Indeed, given the critical role played by low-level spatio-temporal dynamics in the chemistry of the brain, the notion seems to import a radical understanding of the relation between cognition and physical embodiment, one that Clark (2008a) calls *total implementation sensitivity* and that Wheeler (2010b, 2011a, 2013) calls *vital materiality*. According to this understanding, bodily factors make a special, non-substitutable contribution to cognition, meaning that the multiple realizability of the cognitive, and thus functionalism, must fail.⁴

The preceding line of thought is tempting, but ultimately undermotivated. Indeed, we need to take care not to allow the phrase "have to do with the physical setup of the brain" in Collins's specification of embrained knowledge to run away with us. Multiple realizability does not entail that cognition has *nothing* to do with the physical set-up of the brain. How a function is implemented in a physical system may have all kinds of interesting implications for cognitive science, especially (but not only) in areas such as speed, timing and breakdown profile. For example, let's consider some function that is specified in terms of multiple effects. It may be crucial to understanding the precise temporal structure of those effects that we understand them to be achieved via a form of volume signaling in the brain, in which tiny neuromodulators travel not via neural wiring, but freely diffuse through the brain in clouds, pretty much regardless of the surrounding cellular and membrane structures. (For further information on such chemical signaling, see e.g. Husbands, Smith, Jakobi, and O'Shea, 1998.) All this is consistent with the multiple realizability of the cognitive function in question, even if, in certain circumstances, a different implementation would result in explanatorily significant differences in the temporal structure of thought or behavior. But if "having to do with the physical setup of the brain" does not undermine multiple realizability, then it doesn't necessarily establish the more radical relation between cognition and embodiment that was attracting our revolution-hunting attention.

The sense-making body

Perhaps the seeds of revolution are to be found in a different view of embodiment, one that hails ultimately from contemporary European phenomenology (especially Merleau-Ponty, 1945/1962), but which has had an important influence in some regions of embodied cognition research (e.g. Gallagher, 2005). From this alternative perspective, the body is conceived as the pre-reflective medium by which the world is opened up in lived experience as a domain of value and significance. Crucially, advocates of this style of embodiment (e.g. Dreyfus, 1996) standardly hold that its role in our sense-making practices cannot be understood in representational terms. Given the plausibility of the general thought that representation is necessary for computation, if the sense-making body cannot be understood in representational terms, then neither can it be understood in computational terms. So an embodied cognitive science built on this notion of embodiment would be a revolutionary threat to the received explanatory framework. But how does the challenge to representation get off the ground? Exhibit one in this debate is the so-called *problem of relevance*.

Arguably one of the most remarkable capacities that human beings possess is our fluid and flexible sensitivity to what is, and what is not, contextually relevant in some situation, a capacity which is typically operative, even in the sort of dynamically shifting and open-ended scenarios in which we often find ourselves. Cognitive science ought to explain this capacity, and to do so in a wholly scientific manner (i.e. without appeal to some magical, naturalistically undischarged relevance detector). This is the problem of relevance, also known (in AI) as the frame problem (see e.g. Shanahan, 2009).

If one approaches the problem of relevance from the perspective of orthodox cognitive science, and thus of any view such as extended functionalism that buys into the same fundamental principles, the difficulty manifests itself as the dual problem of how to retrieve just those behavior-guiding internal representations that are contextually appropriate, and how to update those representations in contextually appropriate ways. But how is the computational agent able to locate the relevant, and only the relevant, representations? The natural representationalist thought is that context itself should be modeled. In other words, the agent should deploy context-specifying representations to determine which of her other stored representations are currently relevant. What is wrong with this strategy? According to Dreyfus (1990, with more than a nod to Heidegger), the root problem is this: any attempt to determine the relevance of representational structures using other representational structures is an invitation to an infinite regress, since those latter representational structures will need to have their own contextual relevance specified by further representations. But these new representations will need to have their contextual relevance specified by yet further representations, and so on.

Dreyfus's conclusion is that the problem of relevance is an artifact of representationalism (Dreyfus, 2008, p. 358). So whatever neutralizes that problem must be non-representational in character. One way to unpack this idea is through Merleau-Ponty's (1945/1962) notion of the *intentional arc*, according to which skills are not represented, but are realized as contextually situated solicitations by one's environment (Dreyfus, 2008, p. 340). To borrow an example from Gallagher (2008), when poised to engage in the action of climbing a mountain, the skilled climber does not build a cognitive representation of the mountain and infer from that plus additionally represented knowledge of her own abilities that it is climbable by her. Rather, from a certain distance, in particular visual conditions, the mountain "simply" looks climbable to her. Her climbing know-how is "sedimented" in how the mountain looks to her. The mountain solicits climbing from her.

Rietveld (2012) puts some flesh on this skeleton, by drawing a distinction between different kinds of *affordance* (Gibson's term for the possibilities for action presented by the environment; Gibson, 1979). It is here that the connection with our more radical species of embodiment is

finally exposed. Given a specific situation, some affordances are mere possibilities for action, where “mere” signals the fact that although the agent *could* respond to them, such a response would be contextually inappropriate. For example, the table at which I am working affords “dancing on top of,” but that possibility is not a feature of my current paper-writing context, so right now I am not primed to respond to it. Some affordances, however, precisely because they are either directly contextually relevant to the task at hand, or have proved to be relevant in similar situations in the past, prime us for action by being what Rietveld calls *bodily potentiating*. It is affordances of the latter sort that are identified by Rietveld as different kinds of Merleau-Pontian solicitation. Figure solicitations are those with which we are actively concerned. For example, in my current paper-writing context, my keyboard summons typing from me. Ground solicitations are those with which we are not currently concerned, but for which we are currently bodily potentiated, and which are thus poised to summon us to act. For example, the teacup on my table that is peripheral with respect to my current focus of activity is nevertheless a feature of my paper-writing context and so is poised to summon me to act in appropriate ways. Human relevance-sensitivity is thus explained by shifting affordance landscapes, by varying patterns of active and body-potentiating solicitations.

Conceived on the Rietveld model, affordances depend constitutively, at least in part, on the kinds of bodies that we have, bodies that can dance, type, grip and lift. So if Dreyfus is right that the skills that explain relevance-sensitivity are realized by our non-representational ability to respond to contextually situated solicitations, and if that non-representational capacity is essentially embodied in the way suggested by Rietveld’s affordance-based analysis, then the notion of embodiment that will explain a central feature of cognition is one that will fuel the fires of revolution in cognitive science.

So far so good, but if the present conception of embodiment is to have any traction in cognitive science, its advocates will need to say rather more about the naturalistically acceptable processes that causally explain solicitation and summoning. The most developed story here hails from Dreyfus (2008), who suggests that the solution lies with something like Freeman’s neuro-dynamical framework (Freeman, 2000). According to Freeman, the brain is a non-representational dynamical system primed by past experience to actively pick up and enrich significance, a system whose constantly shifting attractor landscape causally explains how newly encountered significances may interact with existing patterns of inner organization to create new global structures for interpreting and responding to stimuli. Now, it may well be plausible that a Freeman-esque capacity for bottom-up, large-scale, adaptive reconfiguration, avoiding debilitating context-specifying representations, will be part of a naturalistic solution to the problem of relevance. But the fact remains that the all-important holistic reconfigurations of the attractor landscape that are at the heart of things here need to be explained in a way that doesn’t smuggle in a magic relevance detector. In relation to this demand, Dreyfus appeals to shifts in attention that are correlated with the pivotal reconfigurations (Dreyfus, 2008, p. 360), but this doesn’t seem to do enough work (Wheeler, 2010c). For if the attentional shift is the *cause* of a reconfiguration, then the relevance-sensitivity itself remains unexplained, since shifts in attention are at least sometimes presumably governed by, and so presuppose, sensitivity to what is relevant. But if the attentional shift is an *effect* of the reconfiguration, then we are still owed an explanation of how it is that the relevant attractor is the one that is selected. In sum, the account of relevance-sensitivity on offer from the perspective of Merleau-Pontian, sense-making embodiment may well be revolutionary (non-representational, non-computational) in its implications, but it is dangerously incomplete, because it fails to deliver a compelling causal explanation of the phenomenon at issue. Indeed, the shortfall here is serious enough that one might wonder whether it constitutes a genuine advance over the representationalist alternative.

Breaking the tie

At first sight, the result of our deliberations is an honorable draw, between the reformist embodiment of extended functionalism and the revolutionary embodiment of the sense-making view. After all, neither has a cast-iron solution to the problem of relevance. At this point, however, what ought to kick in is a perfectly healthy methodological principle regarding theory change in science, namely that we should give our support to the competitor theory that requires the less extensive revision of our established explanatory principles, unless we have good reason not to; and that means that, on the strength of the evidence and arguments considered here, the deciding vote goes to extended functionalism, which rejects internalism, while maintaining a conception of the body as an implementational substrate for functionally specified cognitive states and processes that is comfortably familiar from orthodox representational-computational cognitive science. The right conclusion, then, is that the most plausible of the embodied views that we have canvassed today is, in a theoretically important sense, the least embodied of them all.

Acknowledgements

Some passages in this chapter have been adapted with revision from Wheeler, 2011a, 2011c, 2013; Wheeler and Di Paolo, 2011.

Notes

- 1 The still-canonical presentation of ExC is by Clark and Chalmers (1998). Clark's own more recent treatment may be found in Clark, 2008b. For a field-defining collection that places the original Clark and Chalmers paper alongside a range of developments, criticisms and defenses of the notion of extended cognition, see Menary, 2010.
- 2 The case for embedded cognition has been made repeatedly. For just two of the available philosophical treatments, see Clark, 1997, and Wheeler, 2005.
- 3 In this chapter I assume that the notion of multiple realizability is clear and in good order, but I note that not everyone shares my confidence (see e.g. Shapiro, 2000; Milcowski, 2013).
- 4 Here I explore only one way in which vital materiality might be motivated. For critical discussion of certain other routes to that position, see Wheeler, 2010b, 2011a, 2013.

References

- Adams, F., and Aizawa, K. (2008). *The bounds of cognition*. Malden, MA: Blackwell.
- Bechtel, W. (1996). What knowledge must be in the head in order to acquire language. In B. Velichkovsky and D. M. Rumbaugh (Eds.), *Communicating meaning: The evolution and development of language*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Clark, A. (1989). *Microcognition: Philosophy, cognitive science, and parallel distributed processing*. Cambridge, MA: MIT Press.
- (1997). *Being there: Putting brain, body, and world together again*. Cambridge, MA: MIT Press.
- (2008a). Pressing the flesh: A tension in the study of the embodied, embedded mind? *Philosophy and Phenomenological Research*, 76(1), 37–59.
- (2008b). *Supersizing the mind: Embodiment, action, and cognitive extension*. New York: Oxford University Press.
- Clark, A., and Chalmers, D. (1998). The extended mind. *Analysis*, 58(1), 7–19.
- Collins, H. (2000). Four kinds of knowledge, two (or maybe three) kinds of embodiment, and the question of artificial intelligence. In M. Wrathall and J. Malpas (Eds.), *Heidegger, coping and cognitive science: Essays in honor of Hubert L. Dreyfus* (Vol. 2, pp. 179–95). Cambridge, MA: MIT Press.
- Dale, K., and Husbands, P. (2010). The evolution of reaction-diffusion controllers for minimally cognitive agents. *Artificial Life*, 16(1), 1–19.

- Dreyfus, H. L. (1990). *Being-in-the-world: A commentary on Heidegger's being and time, Division I*. Cambridge, MA: MIT Press.
- (1996). The current relevance of Merleau-Ponty's phenomenology of embodiment. *Electronic Journal of Analytic Philosophy*, 4(3). Retrieved from <http://ejap.louisiana.edu/EJAP/1996.spring/dreyfus.1996.spring.html>
- , (2008). Why Heideggerian AI failed and how fixing it would require making it more Heideggerian. In P. Husbands, O. Holland, and M. Wheeler (Eds.), *The mechanical mind in history* (pp. 331–71). Cambridge, MA: MIT Press.
- Freeman, W. (2000). *How brains make up their minds*. New York: Columbia University Press.
- Gallagher, S. (2005). *How the body shapes the mind*. Oxford: Oxford University Press.
- (2008). Are minimal representations still representations? *International Journal of Philosophical Studies*, 16(3), 351–69.
- Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.
- Husbands, P., Smith, T., Jakobi, N., and O'Shea, M. (1998). Better living through chemistry: Evolving GasNets for robot control. *Connection Science*, 10, 185–210.
- Menary, R. (Ed.) (2010). *The extended mind*. Cambridge, MA: MIT Press.
- Merleau-Ponty, M. (1945/1962). *Phenomenology of perception*. London: Routledge.
- Milcowski, M. (2013). *Explaining the computational mind*. Cambridge, MA: MIT Press.
- Newell, A., and Simon, H. A. (1976). Computer science as empirical inquiry: Symbols and search. *Communications of the Association for Computing Machinery*, 19(3), 113–26.
- Rietveld, E. (2012). Context-switching and responsiveness to real relevance. In J. Kiverstein and M. Wheeler (Eds.), *Heidegger and cognitive science* (pp. 105–34). Basingstoke: Palgrave Macmillan.
- Rupert, R. (2009). *Cognitive systems and the extended mind*. Oxford: Oxford University Press.
- Searle, J. R. (1980). Minds, brains, and programs. *Behavioral and Brain Sciences*, 3(3), 417–57.
- Shanahan, M. (2009). The frame problem. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Winter 2009 ed.). Retrieved 25 October 2013, from <http://plato.stanford.edu/archives/win2009/entries/frame-problem/>
- Shapiro, L. A. (2000). Multiple realizations. *Journal of Philosophy*, 97(12), 635–54.
- Turing, A. M. (1950). Computing machinery and intelligence. *Mind*, 59, 433–60. Repr. in M. A. Boden (Ed.), *The philosophy of artificial intelligence* (pp. 40–66). Oxford: Oxford University Press, 1990. (Page references to the repr. ed.)
- Wheeler, M. (2005). *Reconstructing the cognitive world: The next step*. Cambridge, MA: MIT Press.
- (2010a). In defense of extended functionalism. In R. Menary (Ed.), *The extended mind* (pp. 245–70). Cambridge, MA: MIT Press.
- (2010b). Minds, things, and materiality. In L. Malafouris and C. Renfrew (Eds.), *The cognitive life of things: Recasting the boundaries of the mind* (pp. 29–37). Cambridge: McDonald Archaeological Institute.
- (2010c). Plastic machines: Behavioural diversity and the turing test. *Kybernetes*, 39(3), 466–80.
- (2011a). Embodied cognition and the extended mind. In J. Garvey (Ed.), *The Continuum companion to philosophy of mind* (pp. 220–38). London: Continuum.
- (2011b). In search of clarity about parity. *Philosophical Studies*, 152(3), 417–25.
- (2011c). Thinking beyond the brain: Educating and building from the standpoint of extended cognition. *Computational Culture*, 1. Retrieved from <http://computationalculture.net/article/beyond-the-brain>
- (2013). What matters: Real bodies and virtual worlds. In I. Harvey, A. Cavoukian, G. Tomko, D. Borrett, H. Kwan, and D. Hatzinakos (Eds.), *SmartData: Privacy meets evolutionary robotics* (pp. 69–80). Berlin: Springer.
- Wheeler, M., and Di Paolo, E. (2011). Existentialism and cognitive science. In F. Joseph, J. Reynolds, and A. Woodward (Eds.), *Continuum companion to existentialism* (pp. 241–59). London: Continuum.

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