Philosophical Psychology
Lecture 01: Intention and Motor Representation in Purposive Action

Stephen A. Butterfill
<s.butterfill@warwick.ac.uk>

October 5, 2017

title-slide Any attempt to bring scientific discoveries about action into a philosophical discussion quickly runs into a significant obstacle … [The obstacle will be apparently completely different way of thinking about action.]

slide-3 Which events are actions? In philosophy, answering this question would typically answered by appeal to intention or practical reasoning.

Such views tend to be neutral on how the attitudes and processes ultimately connect to bodily movements; that is considered to be merely an implementation detail …

They are neutral in this sense: the views do not depend in any way on facts about that distinguish one kind of body from another, or on facts about how the body's movements are ultimately controlled …

slide-4 In cognitive science … little to say about actions whose purposes involve things the motor system doesn't care about—your motor system doesn't care whether the plane you are stepping is headed for Milan or for Rome, but this sort of difference can affect whether your actions succeed or fail.

———

slide-5 You might just say that the two disciplines are talking past each other, or you might say that they are offering two complementary but independent models of action.

Call this the 'Two Stories View' (or divorced, but living together).

But we want to argue that these two views are components of a single, larger story about action. Although intention and motor representation can usefully be studied in isolation to some extent, a full understanding of action will require understanding interfaces between the two …

But first let me fill in a little detail about each of the stories …

slide-6 Intentions and motor representations belong to quite different enterprises, I think.

WHY MOTOR REPRESENTATION? ONE ADVANTAGE OF THEORISING ABOUT MOTOR REPRESENTATIONS IS THAT YOU CAN GENERATE TESTABLE PREDICTIONS. INTENTIONS ARE FICTIONS. YOU CANNOT GENERATE TESTABLE PREDICTIONS FROM A THEORY ABOUT INTENTION. SO IF YOUR QUESTION IS ABOUT WHAT ENABLES COOPERATION, YOU WILL PROBABLY NEED A STORY ABOUT PSYCHOLOGICAL MECHANISMS.

ONTOLOGY : YOU WOULDN'T DO IT WITHOUT THINKING ABOUT PHYSICS, WOULD YOU? SOCIAL ONTOLOGY NEEDS PSYCHOLOGY LIKE ONTOLOGY NEEDS PHYSICS.

slide-9 Gilbert is explicit about this. What grounds her theorising>

This is fine. But it doesn't involve anything measurable or repeatable. You will never be able to generate any testable predictions. So you are quite unlikely to be on the path to discovering about how things work.

Which is fine if you're Gilbert, of course, because she has no such aim. But if you're me, you want to know how things work.

intro_to_intention

Intention

What are intentions and what is their role in practical reasoning and action? Some basic distinctions from the Philosophy of Action can give us a fix on the notion of intention as many philosophers conceive of it.

slide-11 You tilt the bottle thereby pouring prosecco all over Zac's trousers. You might say, the goal of my actions was not to soak Zac's trousers but to fill his glass.

slide-12 As this illustrates, some actions involving are purposive in the sense that

slide-13 among all their actual and possible consequences, slide-14 there are outcomes to which they are directed

In such cases we can say that the actions are clearly purposive.

slide-15 Concerning any such actions, we can ask What is the relation between a purposive action and the outcome or outcomes to which it is directed?

slide-16 The standard answer to this question involves intention.

slide-17 An intention (1) specifies an outcome,

slide-18 (2) coordinates the one or several activities which comprise the action;

and (3) coordinate these activities in a way that would normally facilitate the outcome's occurrence.

What binds particular component actions together into larger purposive actions? It is the fact that these actions are all parts of plans involving a single intention. What singles out an actual or possible outcome as one to which the component actions are collectively directed? It is the fact that this outcome is represented by the intention.

So the intention is what binds component actions together into purposive actions and links the action taken as a whole to the outcomes to which they are directed.

slide-19 But is intention the only thing that can link actions to outcomes? I will suggest that motor representations can likewise perform this role.

slide-20 Any questions or remarks?

I wonder if anyone wants to say something about this story and whether it answers the question, What is the relation between a purposive action and the outcome or outcomes to which it is directed? (I think it does and no one has so far objected to it except on very broad theoretical grounds involving Anscombe.)

Or maybe there's a basic question about intention.

intro_to_motor_representation

Motor Representation

Motor representations are involved in performing and preparing actions. Not all representations represent patterns of joint displacements and bodily configurations: some represent outcomes such as the grasping of an object, which may be done in different ways in different contexts.

slide-22 Let me go back and start with some almost uncontroversial facts about motor representations and their action-coordinating role.

Why postulate motor representations at all? [Dependence of present actions on future actions is one reason for doing so.]

slide-23 Suppose you are a cook who needs to take an egg from its box, crack it and put it (except for the shell) into a bowl ready for beating into a carbonara sauce. Even for such mundane, routine actions, the constraints on adequate performance can vary significantly depending on subtle variations in context. For example, the position of a hot pan may require altering the trajectory along which the egg is transported, or time pressures may mean that the action must be performed unusually swiftly on this occasion. Further, many of the constraints on performance involve relations between actions occurring at different times. To illustrate, how tightly you need to grip the egg now depends, among other things, on the forces to which you will subject the egg in lifting it later. It turns out that people reliably grip objects such as eggs just tightly enough across a range of conditions in which the optimal tightness of grip varies. This indicates (along with much other evidence) that information about the cook's anticipated future hand and arm movements appropriately influences how tightly she initially grips the egg (compare Kawato 1999). This anticipatory control of grasp, like several other features of action performance (see Rosenbaum 2010, chapter 1 for more examples), is not plausibly a consequence of mindless physiology, nor of intention and practical reasoning. This is one reason for postulating motor representations, which characteristically play a role in coordinating sequences of very small scale actions such as grasping an egg in order to lift it.

[The scale of an actual action can be defined in terms of means-end relations. Given two actions which are related as means to ends by the processes and representations involved in their performance, the first is smaller in scale than the second just if the first is a means to the second. Generalising, we associate the scale of an actual action with the depth of the hierarchy of outcomes that are related to it by the transitive closure of the means-ends relation. Then, generalising further, a repeatable action (something that different agents might do independently on several occasions) is associated with a scale characteristic of the things people do when they perform that action. Given that actions such as cooking a meal or painting a house count as small-scale actions, actions such as grasping an egg or dipping a brush into a can of paint are very-small scale. Note that we do not stipulate a tight link between the very small scale and the motoric. In some cases intentions may play a role in coordinating sequences of very small scale purposive actions, and in some cases motor representations may concern actions which are not very small scale. The claim we wish to consider is only that, often enough, explaining the coordination of sequences of very small scale actions appears to involve representations but not, or not only, intentions. To a first approximation, *motor representation* is a label for such representations.[1]]

slide-24 'a given motor act may change both as a function of what motor act will follow it—a sign of planning—and as a function of what motor act preceded it—a sign of memory' (Cohen and Rosenbaum 2004, p. 294).

slide-25 What do motor representations represent? An initially attractive, conservative view would be that they represent bodily configurations and joint displacements, or perhaps sequences of these, only.

slide-26 However there is now a significant body of evidence that some motor representations do not specify particular sequences of bodily configurations and joint displacements, but rather represent outcomes such as the grasping of an egg or the pressing of a switch. These are outcomes which might, on different occasions, involve very different bodily configurations and joint displacements (see Rizzolatti and Sinigaglia 2010 for a selective review).

Such outcomes are abstract relative to bodily configurations and joint displacements in that there are many different ways of achieving them.

slide-28 Since this is important, let me pause for a moment. To say that something is an outcome is not to say very much: merely that it is a possible or actual state of affairs which is brought about in some way by an action.

What I mean is that motor representations represent the sort of outcomes that are plausibly thought of as goals of actions, things such as transporting and breaking an egg, or flipping a switch.

This kind of outcomes are quite different from both patterns of joint displacement and bodily movements and also from end states.

slide-29 In my terms, a goal is merely outcome. Contrast goals with goal-states, which are mental or functional states which specify goals. A motor representation is a goal-state; the goal is the thing it represents.

[1] Much more to be said about what motor representations are; for instance, see Butterfill and Sinigaglia (2014) for the view that motor representations can be distinguished by representational format.

slide-30 Motor schema are just motor representations which specify incomplete outcomes. [Of course schema are incomplete, so do not specify outcomes but outcome types.]

Motor schema are 'internal models or stored representations that represent generic knowledge about a certain pattern of action and are implicated in the production and control of action' (Mylopoulos and Pacherie 2016).

'Motor schemas are more abstract and stable representations of actions than motor representations.'

'They are internal models or stored representations that represent generic knowledge about a certain pattern of action and are implicated in the production and control of action. For instance, in the influential Motor Schema Theory proposed by Richard Schmidt (1975, 2003), a motor schema involves a generalized motor program, together with corre- sponding 'recall' and 'recognition' schemas. The generalized motor program is thought to contain an abstract representation defining the general form or pattern of an action, that is the organization and structure common to a set of motor acts (e.g., invariant features pertaining to the order of events, their spatial configuration, their relative timing and the relative force with which they are produced). This generalized motor program has parameters that control it. In order to determine how an action should be performed on a given occasion, parameter values adapted to the situation must be specified. Thus, a motor schema also includes a rule or system of rules describing the relationships between initial conditions, parameter values and outcomes and allowing us to perform the action over a large range of conditions (the 'recall schema' in Schmidt's terminology). Finally, the motor schema also includes a rule or system of rules describing the relationships between initial conditions, exteroceptive and propri- oceptive sensory feedback during an action, and action outcome (a recognition sche- ma), allowing agents to know when they have made an error – i.e., the action does not have the sensory consequences it is expected to have – and to correct for it.'

Are motor schemas an alterantive to motor representations? Tempting to think that where they talk about motor schema, we think of motor representations that represent outcomes that are relatively distal from action (e.g. are affector-neutral).

This would explain why they contrast motor schema with motor programmes. We use 'motor representation' to include both.

slide-31 A goal represented motorically triggers a process which, via computations of things like end states, starting states and smoothness, eventually results in joint displacements; and when things go well, these joint displacements together with the resulting bodily configurations bring about, or constitute, the occurrence of the goal.

slide-32 But of course this is a simplification. Motor representations can trigger processes which result in further goals being represented, as for example when a motor representation of the transporting of an object triggers representations of reaching, grasping, placing and releasing.

slide-33 The processes linking motor representations are planning like in two respects: (i) means-end …

slide-34 … and (ii) relational constraints

slide-35 But how do we know that motor representations carry information about such outcomes? I'm glad you asked, let me explain …

slide-36 If you were to observe someone phi-ing, then motor representations would occur in you much like those that would occur in you if it were you, not her, who was phi-ing.

This will be a focus of interest in a later session. For now it's just a handy fact that simplifies testing.

slide-38 For a quick illustration of how we know about the double life of motor representation, consider this experiment ….

'Double TMS pulses were applied just prior to stimuli presentation to selectively prime the cortical activity specifically in the lip (LipM1) or tongue (TongueM1) area' (D'Ausilio et al. 2009, p. 381)

'We hypothesized that focal stimulation would facilitate the perception of the concordant phonemes ([d] and [t] with TMS to TongueM1), but that there would be inhibition of perception of the discordant items ([b] and [p] in this case). Behavioral effects were measured via reaction times (RTs) and error rates.' (D'Ausilio et al. 2009, p. 382)

slide-40 'The posterior section of the frontal lobe contains the motor areas,' (p. 4) Now you know as much about the brain as I do.

Mention primary and supplementary motor areas : we use the term 'motor' loosely (compare 'visual', which also has narrower and broader uses in neuroscience).

slide-41 [end of aside on the double life of motor representation]

slide-44 TMS to measure MEP

slide-45 They also had an occluded end version …

slide-46 Incidentally, 'the observed direction of the modulation was not consistent with previous TMS literature. Specifically, MEP amplitudes were significantly lower in the Object-Present than in the Object-Absent conditions (Fig. 2), suggesting that there was an inhibitory effect of object manipulation on the activity of M1 during action observation.'

slide-50 Umiltà et al, 2008 : single cell recordings in monkeys

MEPs (TMS amplified) in humans

slide-51 TMS MEP, humans.

Shown video, then a static picture. Is this the same goal as you saw in the video? Press one of two keys. 'They were explicitly told to ignore the effector and make a judgment on the type of act only.'

slide-52 Key finding: TMS to both ventral premotor cortex (PMv) and left supramarginal gyrus (SMG) increases RTs regardless of whether it's the same effector or a different effector. (You can't see same/different effector in this figure.)

KEY: superior temporal sulcus (STS), and a parietofrontal system consisting of the intraparietal sulcus (IPS) and inferior parietal lobule (IPL) plus the ventral premotor cortex (PMv) and caudal part of inferior frontal gyrus (IFG). In some instances also, the superior parietal lobule (SPL)

slide-53 By contrast, TMS to superior temporal sulcus (STS) increased RT only for judgements where the video effector was the same as the photo effector.

slide-54 The experiments providing such evidence typically involve a marker of motor representation, such as a pattern of neuronal firings, a motor evoked potential or a behavioural performance profile, which, in controlled settings, allows sameness or difference of motor representation to be distinguished. Such markers can be exploited to show that the sameness and difference of motor representation is linked to the sameness and difference of an outcome such as the grasping of a particular object. (Pioneering uses of this method include Rizzolatti et al. 1988, 2001; it has since been developed in many ways: see, for example, Hamilton and Grafton (2008); Cattaneo et al. (2009, 2010); Rochat et al. (2010); Bonini et al. (2010); Koch et al. (2010).)

slide-60 To illustrate, consider a sequence of actions which might be involved in shoplifting an apple: you have to secure the apple, transport it, and position it in your pocket. Each of these outcomes can be represented motorically.

slide-61 Motor processes are planning-like in that they involve computing means from ends. Thus a representation of an end like securing it [the apple] can trigger a process that results in the representation of outcomes that are means to this end.

slide-62 Motor processes are also planning-like in that which means are selected in preparing an action that will occur early in the sequence may affect needs that will arise only later in a later part of the actions. For instance, how the apple is grasped at an early point in the sequence may be determined in part by what would be a more comfortable way for the other hand to grasp it later.

slide-63 So motor representations of outcomes guide planning-like processes. This is why I think it's not just that they carry information about outcomes like grasping an apple, but that they also represent such outcomes.

motor_representations_ground_goals

Motor Representations Ground the Directedness of Actions to Goals

How do intentions ground the purposiveness of actions? On any standard view, an intention represents an outcome, causes an action, and does so in a way that would normally facilitate the outcome's occurrence. Similarly, some motor representations represent action outcomes, play a role in generating actions, and do this in a way that normally facilitates the occurrence of the outcomes represented. Like intentions, motor representations ground the directedness of actions to outcomes which are thereby goals of the actions.

slide-66

slide-67 Now as Elisabeth Pacherie has argued (and I've had a go at arguing this in joint work with Corrado Sinigaglia recently too), motor representations are relevantly similar to intentions. Of course motor representations differ from intentions in some important ways (as Pacherie also notes). But they are similar in the respects that matter for explaining the purposiveness of action. (1) Like intentions, some motor representations represent outcomes (and not merely patters of joint displacement, say). (2) Like intentions, some motor representations play a role in coordinating multiple more component activities by virtue of their role as elements in hierarchically structured plans. (3) And, like intentions, some motor representations coordinate these activities in a way that would normally facilitate the outcome's occurrence. The claim is not that *all* purposive actions are linked to outcomes by motor representations, just that some are. In some cases, the purposiveness of an action is grounded in a motor representation of an outcome; in other cases it is grounded in an intention. And of course in many cases it may be that both intention and motor representation are involved.

slide-68 I started by observing that there are two quite different approaches to answering the question, Which events are actions? What does the ground I've so far tell us about this?

I don't think it tells us much yet (there's much more to come).

First, both stories are stories about purposive actions. So they don't have clearly demarcated domains.

Second, it may make it tempting to think that motor representations are just a kind of intention, and so to take the radical view that there are not really two distinct stories here at all.

motor_representations_arent_intentions

Motor Representations Aren't Intentions

Explains why motor representations aren't intentions.

slide-72 As background we first need a generic distinction between content and format. Imagine you are in an unfamiliar city and are trying to get to the central station. A stranger offers you two routes. Each route could be represented by a distinct line on a paper map. The difference between the two lines is a difference in content.

slide-73 Each of the routes could alternatively have been represented by a distinct series of instructions written on the same piece of paper; these cartographic and propositional representations differ in format. The format of a representation constrains its possible contents. For example, a representation with a cartographic format cannot represent what is represented by sentences such as 'There could not be a mountain whose summit is inaccessible.'[2] The distinction between content and format is necessary because, as our illustration shows, each can be varied independently of the other.

[2] Note that the distinction between content and format is orthogonal to issues about representational medium. The maps in our illustration may be paper map or electronic maps, and the instructions may be spoken, signed or written. This difference is one of medium.

slide-74 Format matters because only where two representations have the same format can they be straightforwardly inferentially integrated.

To illustrate, let's stay with representations of routes. Suppose you are given some verbal instructions describing a route. You are then shown a representation of a route on a map and asked whether this is the same route that was verbally described. You are not allowed to find out by following the routes or by imagining following them. Special cases aside, answering the question will involve a process of translation because two distinct representational formats are involved, propositional and cartographic. It is not be enough that you could follow either representation of the route. You will also need to be able to translate from at least one representational format into at least one other format.

slide-75 How in general can we identify or distinguish representational formats? Because representational formats are typically associated with characteristic performance profiles, it is sometimes possible to infer similarities and differences in representational format from similarities and differences in the processes in which representations feature.

To illustrate, suppose that you have a route representation and I want to work out whether it this representation has a cartographic or propositional format. One way to do this might be to test your performance on different tasks. If the representation is propositional you are likely to be relatively fast at identifying key landmarks but relatively slow at translating the route into a sequence of compass directions; but the converse will be true if your representation is cartographic.

slide-76 The same principle—distinguishing and identifying formats by measuring characteristic processing profile—works for mental representations too.

To illustrate, compare imagining seeing an object moving with actually seeing it move. For this comparison we need to distinguish two ways of imagining seeing. There is a way of imagining seeing which phenomenologically is something like seeing except that it does not necessarily involve being receptive to stimuli. This way of imagining seeing, sometimes called 'sensory imagining', is commonly distinguished from cognitive ways of imagining seeing which might for example involve thinking about seeing. It is this way of imagining seeing an object move that we wish to compare with actually seeing an object move.

slide-77 Imagining seeing an object move and actually seeing an object move have similarities in characteristic performance profile. For instance, whether an object can be seen all at once depends on its size and distance from the perceiver; strikingly, when subjects imagine seeing an object, whether they can imagine seeing it all at once depends in the same way on size and distance (Kosslyn 1978; Kosslyn 1996, p. 99ff).

Also, how long it takes to imagine looking over an object depends on the object's subjective size in the same way that how long it would take to actually look over that object would depend on its subjective size (Kosslyn et al. 1978).

The similarities in characteristic performance profile and the particular patterns of interference are good (if non-decisive) reasons to conjecture that imagining seeing and actually seeing involve representations with a common format.

slide-78 One way of imagining action is phenomenologically something like acting except that such imaginings are not necessarily responsive to the features of actual objects and do not necessarily result in bodily movements.

There is evidence that the way imagining performing an action unfolds in time is similar in some respects to the way actually performing an action of the same type would unfold.

For instance, how long it takes to imagine moving an object is closely related to how long it would take to actually move that object (Decety et al. 1989; Decety 1996; Jeannerod 1994).

In addition, for actions such as grasping the handle of a cup, manipulating the target object in ways that would make the action harder (such as orienting the cup's handle to make it less convenient for you to grasp) make a corresponding difference to the effort involved in imagining performing the action (Parsons 1994; Frak et al. 2001).

slide-79 Contrast imagining rotating a ball with imagining seeing a ball rotate.

As is implied by what we've already said, these have quite different characteristic performance profiles.

How quickly the former can be done is a function of how long it would take the agent to rotate the ball, whereas how quickly the latter can be done depends on how rapidly the ball can rotate and still be perceived as rotating.

Further, in some cases rotating a ball clockwise is easier than rotating it anticlockwise, and so is imagining a ball rotate. By contrast, the effort involved in actually seeing or imagining seeing a ball rotate does not similarly differ depending on direction.

slide-80 It may be objected that performance differences such as these can be explained without appealing to a difference in format. After all, rotating a ball involves an action whereas a ball rotating does not; consequently, imagining the former may be thought to differ from imagining the latter with respect to the contents of the representations involved. Supposing that there are differences in content here and in other cases, could these fully explain differences in performance profile? To see why not, consider two tasks involving mental rotation. Judging the laterality of a rotated letter is thought to involve phenomenologically vision-like imagination (Jordan et al. 2001), whereas judging the laterality of a rotated hand is thought to involve phenomenologically action-like imagination (Parsons 1987; Gentilucci et al. 1998). Ordinary subjects who are asked to judge the laterality of a hand rotated to various degrees are less accurate when the hand's position is biomechanically awkward. By contrast, no such effect occurs for comparable tasks involving letters rather than hands. How could this difference in performance in imagining hands and letters be explained? Consider the claim that the difference in performance can be fully explained by a difference in the content of the representations involved. Initially this might seem plausible because one task involves hands whereas the other involves letters. However, there are subjects who can perform both tasks but whose performance is not different for hands and letters (Fiori et al. 2013). These are subjects suffering Amyotrophic Lateral Sclerosis (ALS), which impairs motor representation (Parsons et al. 1998). Since ALS and ordinary subjects encounter the same stimuli and perform the same tasks, there seems to be no reason (other than our hypothesis about a difference in format) to suppose that the two groups' performance involves representations with different contents. So if the hand-letter difference in performance were entirely explained by a difference in content, we would expect ALS and ordinary subjects to exhibit the same difference in performance. But this is not the case. This is an obstacle to supposing that the hand-letter difference in performance in ordinary subjects could be explained by appeal to content.

slide-81 So far we have been arguing that motor and visual representations differ in format. Why suppose that motor representations also differ in format from intentions? Contrast two ways of imagining taking a shot in basketball, one involving the phenomenologically action-like kind of imagination and the other involving a cognitive kind of imagination. The contrast we require is roughly between the way a former player might imagine this and the way that someone who has only ever read about basketball might imagine it. As we have seen, the way phenomenologically action-like imagination unfolds in time and the amount of effort it involves will depend on bio-mechanical, dynamical and postural constraints, among others. These constraints are closely related to those which govern actually performing such actions (Jeannerod 2001), and some can be altered by acquiring or losing motor expertise. By contrast no such constraints would be expected always to apply where a cognitive kind of imagination is involved. In line with the general strategy of inferring differences in format from differences in characteristic performance profile, we conclude that motor representations differ in format from those involved in cognitive kinds of imagination, which are plausibly propositional.

slide-82

1. Only representations with a common format can be inferentially integrated.
2. Any two intentions can be inferentially integrated in practical reasoning.
3. My intention that I visit the ZiF is a propositional attitude.

Therefore:

4. All intentions are propositional attitudes

But:

5. No motor representations are propositional attitudes.

So:

6. No motor representations are intentions.

slide-86 So my concern was to argue that motor representations aren't intentions.

slide-87 So where does this leave us with respect to our starting point, the 'Two Stories' view?

On the face of it, everything I've said so far is compatible with that View and might even be taken to support it.

But there is a problem …

slide-88 Recall stealing an apple …

slide-89 Imagine you are a hungry shoplifter with a powerful desire for an apple. After carefully considering the pile of apples on the stall, you identify one that can be discretely snatched and form an intention to steal that apple as you casually saunter past the stall. In grasping, transporting and pocketing the apple your movements are controlled by motor representations of these outcomes. So your theft depends on an intention, on some motor representations and on there being a match between the outcome specified by the intention and the outcomes specified by the motor representations.

In short: practical reasoning and motor processes are part of a single story about the performance of action; there must be non-accidental matches between the contents of intentions and motor representations.

So we can't accept the Two Stories View because there must sometimes be content-respecting causal interactions involving intentions and motor representations. Without these, our intentions and motor representations would never non-accidentally have synergistic effects on our actions.

the_interface_problem

The Interface Problem

For a single action, which outcomes it is directed to may be multiply determined by an intention and, seemingly independently, by a motor representation. Unless such intentions and motor representations are to pull an agent in incompatible directions, which would typically impair action execution, there are requirements concerning how the outcomes they represent must be related to each other. This is the interface problem: explain how any such requirements could be non-accidentally met.

slide-91 Imagine that you are strapped to a spinning wheel facing near certain death as it plunges you into freezing water. To your right you can see a lever and to your left there is a button. In deciding that pulling the lever offers you a better chance of survival than pushing the button, you form an intention to pull the lever, hoping that this will stop the wheel. If things go well, and if intentions are not mere epiphenomena, this intention will result in your reaching for, grasping and pulling the lever. These actions—reaching, grasping and pulling—may be directed to specific outcomes in virtue of motor representations which guide their execution. It shouldn't be an accident that, in your situation, you both intend to pull a lever and you end up with motor representations of reaching for, grasping and pulling that very lever, so that the outcomes specified by your intention match those specified by motor representations. If this match between outcomes variously specified by intentions and by motor representations is not to be accidental, what could explain it?

As we have just seen, motor representations specify goals.

slide-92 And of course, so do intentions.

slide-93 Further, many actions involve both intention and motor representation. When, for example, you form an intention to turn the lights out, the goal of flipping the light switch may be represented motorically in you.

The nonaccidental success of our actions therefore depends on the outcomes specified by our intentions and motor representations matching.

slide-94 But how should they match? I think they should match in this sense: the occurrence of the outcome specified by the motor representation would would normally constitute or cause, at least partially, the occurrence of the outcome specified by the intention.

slide-95 Now we have to ask, How are nonaccidental matches possible? If you asked a similar question about desire and intention, the answer would be straightforward: desire and intention are integrated in practical reasoning, so it is no surprise that what you intend sometimes nonaccidentally conforms to what you intend. But we cannot give the same sort of answer in the case of motor representations and intentions because …

slide-96 Intention and motor representation are not inferentially integrated.

Beliefs, desires and intentions are related to the premises and conclusions in practical reasoning. Motor representations are not. Similarly, intentions do not feature in motor processes.

slide-97 Failure of inferential integration follows from the claim that they differ in format and are not translated. But I suspect that more people will agree that there is a lack of inferential integration than that they differ in representational format. (must illustrate format with maps).

slide-98 So this is the Interface Problem: how do the outcomes specified by intentions and motor representations ever nonaccidentally match?

slide-100 Having an intention is neither necessary nor sufficient.

slide-101 Jeannerod 2006, p. 12: 'the term apraxia was coined by Liepmann to account for higher order motor disorders observed in patients who, in spite of having no problem in executing simple actions (e.g. grasping an object), fail in actions involving more complex, and perhaps more conceptual, representations.'

Can people with ideomotor apraxia form intentions?

slide-102 (Mylopoulos and Pacherie 2016, p. 7): 'Typically the result of lesion to SMA or anterior corpus callosum, AHS is a condition in which patients perform complex, goal-oriented movements with their cross-lesional limb that they feel unable to directly inhibit or control. The limb is often disproportionately reactive to environmental stimuli, carrying out habitual behaviors that are inappropriate to the context, e.g., grabbing food from a dinner companion's plate (Della Sala 2005, 606). It is clear from many of the behaviors observed in these cases that the anarchic limb fails to hook up with the agent's intentions.'

In the rest of this talk I'm not going to suggest a solution to the interface problem. Instead, I want to mention some considerations which may complicate attempts to solve it.

slide-103 There isn't a big idea or single theme running through it. I'm just going to present research that I've done in different areas—most or all on action, on joint action and on mind reading.

But the Interface Problem stands exemplifies the sort of thing the course is about. It's how I think of philosophical psychology. Reflection on psychological (and neuroscientific) discoveries raises a question which is philosophically challenging in some way.

So the idea is to start with the discoveries and find broadly philosophical questions arising from what has been discovered so far.

Five Complications

Any attempt to solve the interface problem must surmount at least five complications.

slide-104 This isn't a preliminary to my talk; although I will say something about how to solve the interface problem right at the end, I'm mainly concerned to persuade you that the interface problem is tricky to solve.

slide-105 First consideration which complicates the interface problem: outcomes have a complex anatomy comprising manipulation, target, form and more.

There is evidence that each of these can be represented motorically; and of course these can all be specified by intentions too.

On the targets of actions, as Elisabeth has stressed, motor representations represent not only ways of acting but also targets on which actions might be performed and some of their features related to possible action outcomes involving them (for a review see Gallese & Sinigaglia 2011; for discussion see Pacherie 2000, pp. 410-3). For example visually encountering a mug sometimes involves representing features such as the orientation and shape of its handle in motor terms (Buccino et al. 2009; Costantini et al. 2010; Cardellicchio et al. 2011; Tucker & Ellis 1998, 2001).

One possibility is that the Interface Problem breaks down into questions corresponding to these three different components of outcomes. That is, an account of how the manipuations specified by intentions and motor representations nonaccidentally match might end up being quite different from an account of how the targets or forms match. (I'm not saying this is right, just considering the possibility.)

slide-106 Second consideration which complicates the interface problem: scale. This shows that we can't think of the interface problem merely as a way of intentions setting problems to be solved by motor representations: there may be multiple intentions at different scales, and in some cases an intention may operate at a smaller scale than a motor representation.

Suppose you have an intention to tap in time with a metronome. Maintaining synchrony will involve two kinds of correction: phase and period shifts. These appear appear to be made by mechanisms acting independently, so that correcting errors involves a distinctive pattern of overadjustment. Adjustments involving phase shifts are largely automatic, adjustments involving changes in period are to some extent controlled.

How are period shifts controlled? Importantly this is not currently known. One possibility is that period adjustments can be made intentionally (as Fairhurst et al. 2013, p. 2599 hint); another is that there are a small number of 'coordinative strategies' (Repp and Keller 2008) between which agents with sufficient skill can intentionally switch in something like the way in which they can intentionally switch from walking to running. But either way, there can be two intentions: a larger-scale one to tap in time with a metronome and a smaller-scale one to adjust the tapping which results in a period shift.

slide-107 EP: Skilled piano playing means being able to have intentions with respect to larger units than a novice could manage. But in playing a 3-voice fugue you may need to pay attention to a particular nger in order to keep the voices separate. So you need to be able to attend to both 'large chunks' (e.g. chords) of action and 'small chunks' (e.g. keypresses) simultaneously.

BACKGROUND: Because no one can perform two actions without introducing some tiny variation between them, entrainment of any kind depends on continuous monitoring and ongoing adjustments (Repp 2005, p. 976). One kind of adjustment is a phase shift, which occurs when one action in a sequence is delayed or brought forwards in time. Another kind of adjustment is a period shift; that is, an increase or reduction in the speed with which all future actions are performed, or in the delay between all future adjacent pairs of actions. These two kinds of adjustment, phase shifts and period shifts, appear to be made by mechanisms acting independently, so that correcting errors involves a distinctive pattern of overadjustment.[3] Repp (2005, p. 987) argues, further, that while adjustments involving phase shifts are largely automatic, adjustments involving changes in period are to some extent controlled. One possibility is that period adjustments can be made intentionally (as Fairhurst et al. 2013, p. 2599 hint); another is that there are a small number of 'coordinative strategies' (Repp and Keller 2008) between which agents with sufficient skill can intentionally switch in something like the way in which they can intentionally switch from walking to running.

slide-108 So it is not that intentions are restricted to specifying outcomes which form the head of the means-end hierarchy of outcomes represented motorically. They can also influence aspects of outcomes at smaller scales.

slide-109 Third consideration which complicates the interface problem: dynamics.

It's 'not just how motor representations are triggered by intentions, but how motor representations' sometimes nonaccidentally continue to match intentions as circumstances change in unforeseen ways 'throughout skill execution' (Fridland 2016, p. 19).

Here we need to distinguish different kinds of change. Some changes can be flexibly accommodated motorically without any need for intention to be involved, or even for the agents to be aware of the change. This includes peturbations in the apparent direction of motion while drawing (Fourneret and Jeannerod 1998). But other changes may require a change in intention: circumstances may change in such a way that you wish either to abandon the action altogether, or else switch target midway through.

KEY: in executing an intention you may learn something which causes you to change your intention; for example, you may learn that the action is just too awkward, or that the ball is out of reach. So motor processes can result in discoveries that nonaccidentally cause changes in intention.

This also shows that we can't think of the interface problem merely as a way of intentions 'handing off' to motor representations: in some cases, the matching of motor representations and intentions will nonaccidentally persist.

---

[3] See Schulze et al. (2005, pp. 474–6). Keller et al. (2014) suggest, further, that the two kinds of adjustment involve different brain networks. Note that this view is currently controversial: Loehr and Palmer (2011) could be interpreted as providing evidence for a different account of how entrainment is maintained.

slide-110 These reflections on dynamics (and on scale too[?]) suggest that the interface problem is not a unidirectional but a bidirectional one. The agent who intends probably cannot be blind to the ways in which motor representations structure her actions since the structure is both provides and limits opportunities for interventions.

slide-111 The interface problem is the problem of explaining how there could be nonaccidental matches. But there is a related developmental problem: What is the process by which humans acquire abilities to ensure that their intentions and motor representations sometimes nonaccidentally match?

A solution to the interface problem must provide a framework for answering the corresponding question about development.

slide-112 Imagination: intentions and motor representations can nonaccidentally match not only when we are acting but also when we are merely imagining acting.

slide-114 I started by observing that there are two quite different approaches to answering the question, Which events are actions? Philosophers mostly invoke intention, whereas neuroscientists and cognitive psychologists focus on motor representation.

What are we to make of the disparity? Are the two simply talking about different phenomena? I've offered two considerations which, taken together, suggest that they are not.

slide-115 The first consideration is that

Motor representations ground the directedness of actions to goals.

slide-116 The second consideration is that

Some actions involve both intention and motor representation.

slide-117 Given these two considerations, it seems to me that, in some cases, nonaccidentally successful action requires that motor representations and intentions play a harmonious role in guiding actions. In particular, their contents must match.

But this requirement leads us to a question, which I've called 'The Interface Problem'

How are non-accidental matches possible?

The interface problem is the problem of explaining how there could be nonaccidental matches between motor representations and intentions.

In this talk I haven't tried to solve the problem but merely mentioned five complications which anyone who tries to solve it faces.

The interface problem is complicated by the **anatomy** of outcomes, the varying **scales** at which intentions can specify actions, and by the possibility of nonaccidental **dynamical** matching.

So while various researchers have proposed solutions to the Interface Problem – Pacherie, Shepherd and Butterfill and Sinigaglia, I'm doubtful that any are sufficient.

There's also an obstacle I haven't properly considered here yet. As I said at the start, whereas motor representations are postulates of scientific theories, intentions are, well, of less certain origin. We know what motor representations are because they creatures of our own theories. But talk about intention seems to be rooted in what philosophers think about what Ben thinks about what is going on with Ayesha. Maybe part of what makes the interface problem challenging is that we're taking intentions too seriously.

action_experience

Action Experience

What do you experience when someone acts? According to the Action Index Conjecture, motor representations of outcomes structure experiences, imaginings and (prospective) memories in ways which provide opportunities for attention to actions directed to those outcomes. Forming intentions concerning an outcome can influence attention to the action, which can influence the persistence of a motor representation of the outcome.

Step back and consider the problem more generally. The mind is made up of lots of different, loosely connected systems that work largely independently of each other. To a certain extent it's fine for them to go their own way; and of course since they all get the same inputs (what with being parts of a single subject), there are limits on how separate the ways the go can be. Still, it's often good for them to be aligned, at least eventually.

Experience is what enables there to be nonaccidental eventual alignment of largely independent cognitive systems. This is what experience is for.

Can we think along these lines in the case of action?

What do we experience when someone acts? One possibility is that we experience only bodily configurations, joint displacements and effects characteristic of particular actions. For the purposes of this talk, I will assume that this is wrong. Instead I will assume that we experience not only bodily configurations, joint displacements, sounds and the rest but also goal-directed actions.

What might it mean to experience action?

slide-119 Could action experiences be like visual experiences? This wound imply that there are expeirences of action which stand to motor representations in something like the way that visual experiences stand to visual representations.

slide-120 If this were right, how would it help with the interface problem?

slide-121 Visual representations cause visual experiences, which provide reasons for beliefs.

Beliefs (and desires) influence orientation and attention, and thereby visual representations.

This seems unlikely for several reasons. First, vision involves a particular sensory modality. It would be quite radical to postulate a motor modality.

Second, the interface problem in the case of vision is, I suppose, primarily about how visual representations influence beliefs; you don't want influence in the other direction, or at least not too much. By contrast, influence from intention to motor representation is essential; so vision seems likely to provide a poor for the case of action.

slide-123 what is an object index? Formally, an object index is 'a mental token that functions as a pointer to an object' (Leslie et al. 1998, p. 11). If you imagine using your fingers to track moving objects, an object index is the mental counterpart of a finger (Pylyshyn 1989, p. 68).

The interesting thing about object indexes is that a system of object indexes (at least one, maybe more) appears to underpin cognitive processes which are not strictly perceptual but also do not involve beliefs or knowledge states. While I can't fully explain the evidence for this claim here, I do want to mention one of the experimental tools that is used to investigate the existence of, and the principles underpinning, a system of object indexes which operates between perception and thought ...

[Object indexes are going to come in twice: once as a partial solution to the interface problem, then again as a model for a further conjecture about how it might be solved (the 'action index' conjecture).]

slide-124 Suppose you are shown a display involving eight stationary circles, like this one.

slide-125 Four of these circles flash, indicating that you should track these circles.

slide-126 All eight circles now begin to move around rapidly, and keep moving unpredictably for some time.

slide-127 Then they stop and one of the circles flashes. Your task is to say whether the flashing circle is one you were supposed to track. Adults are good at this task (Pylyshyn and Storm 1988), indicating that they can use at least four object indexes simultaneously.

They can also sometimes specify which direction the object was moving in (*ref).

(*Aside.* That this experiment provides evidence for the existence of a system of object indexes has been challenged. See Scholl (2009, p. 59):

> 'I suggest that what Pylyshyn's (2004) experiments show is exactly what they intuitively seem to show: We can keep track of the targets in MOT, but not which one is which. [...] all of this seems easily explained [...] by the view that MOT is simply realized by split object-based attention to the MOT targets as a set.'

It is surely right that the existence of MOT does not, all by itself, provide support for the existence of a system of object indexes. However, contra what Scholl seems to be suggesting here, the MOT paradigm can be adapated to provide such evidence. Thus, for instance, Horowitz and Cohen (2010) show that, in a MOT paradigm, observers can report the direction of one or two targets without advance knowledge of which targets' directions they will be asked to report.)

slide-128 Object indexes are belief-independent. In this scenario, a patterned square disappears behind the barrier; later a plain black ring emerges. If you consider speed and direction only, these movements are consistent with there being just one object. But given the distinct shapes and textures of these things, it seems all but certain that there must be two objects. Yet in many cases these two objects will be assigned the same object index (Flombaum and Scholl 2006; Mitroff and Alvarez 2007).

slide-129 This system of object indexes does not involve belief or knowledge and may assign indexes to objects in ways that are inconsistent with a subject's beliefs about the identities of objects (e.g. Mitroff et al. 2005; Mitroff and Alvarez 2007)

Object indexes can conflict with beliefs, although they are surely not entirely independent of beliefs because they can influence how attention is allocated.

slide-130 Object indexes can guide ongoing object-directed actions. For example, if you are aiming to catch a moving target, object indexes are supposed to influence where you reach. (*ref!)

slide-131 The fact that object indexes may guide action suggests that they can contribute to solving the interface problem? Suppose you are aiming to catch one of several possible targets. What do you do? You attend to the target. What's going on here?

slide-132 … my conjecture is that this is what is going on.

1. Object indexes enable attention to an object,
2. which enables the formation of an intention,
3. which influences attention to objects,
4. which in turn influences assignments of object indexes,
5. thereby guiding action.

slide-133 Now I want to suggest that we can think of the way things work in the case of object indexes as inspiration for a somewhat analogous idea about how motor representations might contribute to what we experience when someone acts.

What do we experience when someone acts? Perhaps we can answer this question by analogy with the effects of object indexes on experience. There's no perceptual modality linked to objects; instead, a system of object indexes appears to imposes a sort of structure on experience which can influence attention and guide action.

By analogy, we might think that the system of motor representations imposes a sort of structure on experience which can influence attention too.

Earlier I suggested that object indexes provide a partial solution to the interface problem (Object index->attention->intention->attention->object index->action.) Similarly, if experience of things around you presents possible actions by way of structuring, what you need to do to act in a certain way is to attend to a particular action possibility structure.

slide-134 'Action index' conjecture

Motor representations of outcomes structure experiences, imaginings and (prospective) memories

in ways which provide opportunities for attention to actions directed to those outcomes.

Forming intentions concerning an outcome can influence attention to the action,

which can influence the persistence of a motor representation of the outcome.

slide-135 There's one major disanalogy with object indexes. Object indexes are about things which are actually present, whereas the motor representations we are interested in specify possible future outcomes.

This appears to be an objection because on the face of it, it seems that there could not be expeirence of future actions any more than we can experience future events.

So, you might object, the idea that motor representations structure experience is ok if you are merely observing someone act, but it will not help with performing actions.

slide-136 I want to answer this objection in two parts. The first part of the answer is that motor representations may structure not only experiences but also imaginigs, memories and prospective memories.

slide-137 The second part of the answer to the objection is that motor representations of outcomes may structure our experiences of objects. The existence of affordances suggests that this is at least possible.

So here is the idea: What is experienced is an object, not an action or an outcome. So the fact that the action lies in the future and the outcome has not yet occurred is no objection. But the motor representation of the outcome structures the experience of the object in some way. So the overall character of the experience of the mug differs when an action is represented motorically compared to when it does not.

And this difference is structural in the same sense that the difference object indexes make is structural. It's about how elements of experience are organised rather than about any particular sensory modality.

slide-138 A second objection: intentions and motor representations need to match in situations where you merely imagine acting or merely imaginary objects. In such situations there are no objects to experience.

Reply: motor representations structure experiences associated with imaginig things as they do experiences associated with actually perceiving things. To imagine acting on a mug (say), you need to imagine the mug.

A third objection: close your eyes, put yourself in a sensory deprivation chamber. Let your hand rest palm down on a table. Now intend to turn your hand palm up. Often enough, the intention will succeed. But by hypothesis there is nothing you experience (you are in a sensory deprivation chamber).

Two points in reply to this objection: first, we haven't removed proprioception and other somasomatic senses. It may be that motor representations structure experiences of the body just as much as they structure experiences of mere objects.

But what if you remove somasomatic senses too? This is likely to impair action, but unlikely to make it impossible. Perhaps the ability to act in such situations depends on memory and imagination.

slide-139 So far I've suggested that this conjecture (a) might contribute to solving the interface problem and (b) isn't obviously wrong. But how could we tell whether it is right? What predictions does it generate?

slide-140 Prediction 1: it is possible to vary which action someone experiences while holding fixed her perceptual experiences of bodily configurations and joint displacements and their sensory effects.

slide-141

slide-142 In conclusion, the interface problem is the problem of explaining how there could be nonaccidental matches between motor representations and intentions.

The interface problem is complicated by the **anatomy** of outcomes, the varying **scales** at which intentions can specify actions, and by the possibility of nonaccidental **dynamical** matching.

Part (but not all) of the solution to the interface problem may be what I provisionally called the 'action index' conjecture. According to this conjecture, 'Action index' conjecture

Motor representations of outcomes structure experiences, imaginings and (prospective) memories

in ways which provide opportunities for attention to actions directed to those outcomes.

Forming intentions concerning an outcome can influence attention to the action, which can influence the persistence of a motor representation of the outcome.

I'm yet fully convinced that this 'action index' conjecture is the right way to think about action experiences. But what I am convinced of is that if we are going to solve the interface problem, we will need to understand the ways in which actions can be experienced and the mechanisms which make this possible.

References

Bonini, L., Rozzi, S., Serventi, F. U., Simone, L., Ferrari, P. F., and Fogassi, L. (2010). Ventral premotor and inferior parietal cortices make distinct contribution to action organization and intention understanding. *Cerebral Cortex*, 20(6):1372 –1385.

Butterfill, S. A. and Sinigaglia, C. (2014). Intention and motor representation in purposive action. *Philosophy and Phenomenological Research*, 88(1):119–145.

Cattaneo, L., Caruana, F., Jezzini, A., and Rizzolatti, G. (2009). Representation of goal and movements without overt motor behavior in the human motor cortex: A transcranial magnetic stimulation study. *The Journal of Neuroscience*, 29(36):11134 –11138.

Cattaneo, L., Sandrini, M., and Schwarzbach, J. (2010). State-Dependent TMS reveals a hierarchical representation of observed acts in the temporal, parietal, and premotor cortices. *Cerebral Cortex*, 20(9):2252 –2258.

Cohen, R. G. and Rosenbaum, D. A. (2004). Where grasps are made reveals how grasps are planned: generation and recall of motor plans. *Experimental Brain Research*, 157(4):486–495.

D'Ausilio, A., Pulvermüller, F., Salmas, P., Bufalari, I., Begliomini, C., and Fadiga, L. (2009). The Motor Somatotopy of Speech Perception. *Current Biology*, 19(5):381–385.

Decety, J. (1996). Do imagined and executed actions share the same neural substrate? *Cognitive Brain Research*, 3(2):87–93.

Decety, J., Jeannerod, M., and Prablanc, C. (1989). The timing of mentally represented actions. *Behavioural Brain Research*, 34(1-2):35–42.

Fairhurst, M. T., Janata, P., and Keller, P. E. (2013). Being and feeling in sync with an adaptive virtual partner: Brain mechanisms underlying dynamic cooperativity. *Cerebral Cortex*, 23(11):2592–2600.

Fiori, F., Sedda, A., Ferrè, E. R., Toraldo, A., Querzola, M., Pasotti, F., Ovadia, D., Piroddi, C., Dell'acquila, R., Lunetta, C., Corbo, M., and Bottini, G. (2013). Exploring motor and visual imagery in amyotrophic lateral sclerosis. *Experimental Brain Research*, 226(4):537–547.

Flombaum, J. I. and Scholl, B. J. (2006). A temporal same-object advantage in the tunnel effect: facilitated change detection for persisting objects. *Journal of Experimental Psychology. Human Perception and Performance*, 32(4):840–853.

Fourneret, P. and Jeannerod, M. (1998). Limited conscious monitoring of motor performance in normal subjects. *Neuropsychologia*, 36(11):1133–1140.

Frak, V., Paulignan, Y., and Jeannerod, M. (2001). Orientation of the opposition axis in mentally simulated grasping. *Experimental Brain Research*, 136(1):120–127.

Fridland, E. (2016). Skill and motor control: Intelligence all the way down. *Philosophical Studies*, pages 1–22.

Gentilucci, M., Daprati, E., and Gangitano, M. (1998). Right-handers and left-handers have different representations of their own hand. *Cognitive Brain Research*, 6(3):185–192.

Hamilton, A. and Grafton, S. T. (2008). Action outcomes are represented in human inferior frontoparietal cortex. *Cerebral Cortex*, 18(5):1160–1168.

Horowitz, T. S. and Cohen, M. A. (2010). Direction information in multiple object tracking is limited by a graded resource. *Attention, Perception, & Psychophysics*, 72(7):1765–1775.

Jeannerod, M. (1994). The representing brain: Neural correlates of motor intention and imagery. *Behavioral and Brain Sciences*, 17(2):187–245.

Jeannerod, M. (2001). Neural simulation of action: A unifying mechanism for motor cognition. *NeuroImage*, 14(1):S103–S109.

Jordan, K., Heinze, H., Lutz, K., Kanowski, M., and Jäncke, L. (2001). Cortical activations during the mental rotation of different visual objects. *Neuroimage*, 13(1):143–152.

Kawato, M. (1999). Internal models for motor control and trajectory planning. *Current Opinion in Neurobiology*, 9(6):718–727.

Keller, P. E., Novembre, G., and Hove, M. J. (2014). Rhythm in joint action: psychological and neurophysiological mechanisms for real-time interpersonal coordination. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 369(1658):20130394.

Koch, G., Versace, V., Bonnì, S., Lupo, F., Gerfo, E. L., Oliveri, M., and Caltagirone, C. (2010). Resonance of cortico–cortical connections of the motor system with the observation of goal directed grasping movements. *Neuropsychologia*, 48(12):3513–3520.

Kosslyn, S., Ball, T., and Reiser, B. (1978). Visual images preserve metric spatial information: Evidence from studies of image scanning. *Journal of experimental psychology: Human perception and performance*, 4(1):47.

Kosslyn, S. M. (1978). Measuring the visual angle of the mind's eye. *Cognitive Psychology*, 10(3):356–389.

Kosslyn, S. M. (1996). *Image and Brain: The Resolution of the Imagery Debate.* MIT Press.

Leslie, A. M., Xu, F., Tremoulet, P. D., and Scholl, B. J. (1998). Indexing and the object concept: Developing 'what' and 'where' systems. *Trends in Cognitive Sciences*, 2(1).

Loehr, J. D. and Palmer, C. (2011). Temporal coordination between performing musicians. *The Quarterly Journal of Experimental Psychology*, 64(11):2153–2167.

Mitroff, S. R. and Alvarez, G. A. (2007). Space and time, not surface features, guide object persistence. *Psychonomic Bulletin & Review*, 14(6):1199–1204.

Mitroff, S. R., Scholl, B. J., and Wynn, K. (2005). The relationship between object files and conscious perception. *Cognition*, 96(1):67–92.

Mylopoulos, M. and Pacherie, E. (2016). Intentions and Motor Representations: The Interface Challenge. *Review of Philosophy and Psychology*, forthcoming:1–20.

Parsons, L. (1987). Imagined spatial transformations of one's hands and feet. *Cognitive Psychology*, 19(2):178–241.

Parsons, L., Gabrieli, J., Phelps, E., and Gazzaniga, M. (1998). Cerebrally lateralized mental representations of hand shape and movement. *The Journal of neuroscience*, 18(16):6539–6548.

Parsons, L. M. (1994). Temporal and kinematic properties of motor behavior reflected in mentally simulated action. *Journal of Experimental Psychology. Human Perception and Performance*, 20(4):709–730.

Pylyshyn, Z. W. (1989). The role of location indexes in spatial perception: A sketch of the FINST spatial-index model. *Cognition*, 32(1):65–97.

Pylyshyn, Z. W. and Storm, R. W. (1988). Tracking multiple independent targets: Evidence for a parallel tracking mechanism. *Spatial Vision*, 3(3):179–197.

Repp, B. H. (2005). Sensorimotor synchronization: A review of the tapping literature. *Psychonomic Bulletin & Review*, 12(6):969–992.

Repp, B. H. and Keller, P. E. (2008). Sensorimotor synchronization with adaptively timed sequences. *Human Movement Science*, 27(3):423–456.

Rizzolatti, G., Camarda, R., Fogassi, L., Gentilucci, M., Luppino, G., and Matelli, M. (1988). Functional organization of inferior area 6 in the macaque monkey. *Experimental Brain Research*, 71(3):491–507.

Rizzolatti, G., Fogassi, L., and Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews: Neuroscience*, 2(9):661–670.

Rizzolatti, G. and Sinigaglia, C. (2010). The functional role of the parieto-frontal mirror circuit: interpretations and misinterpretations. *Nature Reviews: Neuroscience*, 11(4):264–274.

Rochat, M. J., Caruana, F., Jezzini, A., Escola, L., Intskirveli, I., Grammont, F., Gallese, V., Rizzolatti, G., and Umiltà, M. A. (2010). Responses of mirror neurons in area f5 to hand and tool grasping observation. *Experimental Brain Research*, 204(4):605–616.

Rosenbaum, D. A. (2010). *Human motor control.* Academic Press, San Diego, CA, US, 2nd edition.

Scholl, B. J. (2009). What have we learned about attention from multiple-object tracking (and vice versa)? In *Computation, cognition, and Pylyshyn*, pages 49–77. MIT Press, Cambridge, MA.

Schulze, H.-H., Cordes, A., and Vorberg, D. (2005). Keeping synchrony while tempo changes: Accelerando and ritardando. *Music Perception: An Interdisciplinary Journal*, 22(3):461–477.