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Psychological research on joint action: Theory and data

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## 1. Introduction

Human life is full of joint actions ranging from a handshake to the performance of a symphony (Clark, 1996). As Woodworth (1939, p. 823) pointed out, in many or all cases of joint action it is not possible to fully understand the individuals' actions in isolation from each other: 'Two boys, between them, lift and carry a log which neither could move alone. You cannot speak of either boy as carrying half the log [...]. Nor can you speak of either boy as half carrying the log [...]. The two boys, coordinating their efforts upon the log, perform a joint action and achieve a result which is not divisible between the component members of this elementary group.'

How, then, can the basic processes enabling people to perform actions together be studied through psychological experiments? What are the perceptual, cognitive, and motor processes that enable individuals to coordinate their actions with others, and how can the seemingly irreducible components of joint actions (Hutchins, 1995) be characterized? This article provides an overview of current theories and experiments in psychology that have substantially enhanced our understanding of joint action.

Generally, a joint action is a social interaction whereby two or more individuals coordinate their actions in space and time to bring about a change in the environment (Sebanz, Bekkering, & Knoblich, 2006). Coordinating one's actions with others to achieve a joint outcome, such as lifting a basket together and placing it on a table, seems to require some kind of interlocking of individuals' behaviours, motor commands, action plans, perceptions, or intentions. Early approaches to joint action originate in philosophers' interest in the nature of joint intentionality. These approaches specify representational systems that enable the planning of joint actions.

Philosophers generally agree that joint actions are actions done with shared intentions: what distinguishes joint actions from individual actions is that the joint ones involve a shared

intention, and shared intentions are essential for understanding coordination in joint action. This conceals deep disagreement on what shared intentions are. Some hold that shared intentions differ from individual intentions with respect to the attitude involved (Kutz, 2000; Searle, 1990 [2002]). Others have explored the notion that shared intentions differ with respect to their subjects, which are plural (Gilbert, 1992), or that they differ from individual intentions in the way they arise, namely through team reasoning (Gold & Sugden, 2007), or that shared intentions involve distinctive obligations or commitments to others (Gilbert, 1992; Roth, 2004). Opposing all such views, Michael Bratman (1992, 2009) argues that shared intentions can be realised by multiple ordinary individual intentions and other attitudes whose contents interlock in a distinctive way (see Tollefsen 2005).

The philosophical work on joint intentionality has guided research on language use where language is conceived of as a form of joint action (Brennan & Hanna, 2009; Clark, 1996). Focusing on common perceptions, common knowledge, and communicative signals, this approach situates joint planning in particular environments and particular interaction histories. For instance, the analysis of joint actions such as assembling furniture together or playing a piano duet has revealed how speech is used to pre-specify who will do what and to agree on the specifics of the joint performance (Clark, 2005). Studies addressing how people solve spatial coordination problems have demonstrated that humans readily invent new symbol systems to coordinate their actions if conventional communication is not an option (Galantucci, 2009).

The philosophical work on joint intentionality has also inspired groundbreaking research on the phylogenetic and ontogenetic roots of joint action and social understanding (Call, 2009; Carpenter, 2009; Tomasello, 2009). Melis, Hare, and Tomasello (2006) found that chimpanzees understand when they need to elicit the help of a conspecific to retrieve food and select the best collaborators to support their actions. This indicates that humans are not

the only species to possess a representational system to support the planning of joint actions. However, it seems that humans are especially prone ('have a special motivation', Tomasello, 2009) to engage in joint action and to help others to achieve their goals (Brownell, Ramani, & Zervas, 2006). For instance, one-year-old infants perform actions to help adults attain their goals (Warneken & Tomasello, 2007) and gesture helpfully to provide relevant information (Liszkowski, Carpenter, & Tomasello, 2008). By three years children understand that joint action implies commitment of the individual partners (Graefenhain, Behne, Carpenter, & Tomasello, 2009).

Research on perception, action, and cognitive control has focused on the nuts and bolts of joint action addressing the perceptual, cognitive, and motor mechanisms of planning and coordination. Ecological psychologists have studied rhythmic joint actions in order to determine whether dynamical principles of intrapersonal coordination scale up to the interpersonal case (Marsh, Richardson, & Schmidt, 2009). This research has shown that in many cases the movement of limbs belonging to different people follows the same mathematical principles as the movement of an individual's limbs (e.g., Schmidt, Carello, & Turvey, 1990). Cognitive psychologists have studied how co-actors represent each other's tasks and how the ability to predict each other's actions supports coordination in real time (Sebanz et al., 2006). The results of this research suggest that specific perceptual, motor, and cognitive processes support joint action (Knoblich & Sebanz, 2008; Semin & Smith, 2008) and that the needs of joint action shape individual perception, action, and cognition (Knoblich & Sebanz, 2006).

The present article provides a review of recent joint action research with a focus on the nuts and bolts of joint action. We begin by outlining a set of processes of emergent and planned coordination that support interpersonal coordination during joint action. We then review studies that have addressed particular processes of emergent coordination and planned

coordination. In the last part of the article we discuss evidence that could lead to an improved understanding of the interplay between planned and emergent coordination in enabling effective joint action.

## 2. Emergent and planned coordination

We distinguish between two types of coordination that can occur during joint action, planned coordination and emergent coordination. In planned coordination agents' behaviour is driven by representations that specify the desired outcomes of joint action and the agent's own part in achieving these outcomes. How much is specified about other agents' tasks, perceptions, and knowledge may vary greatly. An agent may consider others' motives, thoughts, or perspectives, or simply wait for a particular action to happen (Vesper, Butterfill, Knoblich, & Sebanz, in press).

In emergent coordination (EC), coordinated behaviour occurs due to perception-action couplings that make multiple individuals act in similar ways; it is independent of any joint plans or common knowledge (which may be altogether absent). Rather, agents may process perceptual and motor cues in the same way as each other. Two separate agents may start to act as a single coordinated entity (Marsh et al., 2009; Spivey, 2007) because common processes in the individual agents are driven by the same cues and motor routines.

### 2.1 Emergent coordination

Emergent coordination can occur spontaneously between individuals who have no plan to perform actions together as well as during planned joint actions. For instance, pedestrians often fall into the same walking patterns (Van Ulzen et al., 2008) and people engaged in conversation synchronize their body sway (Shockley, Santana, & Fowler, 2003) and mimic

each other's mannerisms (Chartrand & Bargh, 1999). In all of these instances of emergent coordination similar behaviours occur spontaneously in two agents. Because these similarities don't seem instrumental for either individual goals or joint goals, emergent coordination has sometimes been portrayed as a single process (Semin & Cacioppo, 2007). However, if (as we believe) emergent coordination is a key facilitator of joint action then it is essential to distinguish different sources of emergent coordination. We will distinguish between four such sources, 1) entrainment, 2) common affordances, 3) perception action matching, and 4) action simulation.

### *Entrainment*

Entrainment is perhaps the most widely studied social motor coordination process (Schmidt, Fitzpatrick, Caron, & Mergeche, in press). For instance, two people in rocking chairs involuntarily synchronize their rocking frequencies (Richardson, Marsh, Eisenhower, Goodman, & Schmidt, 2007), and audiences in theatres tend to clap in unison (Néda, Ravasz, Brechet, Vicsek, and Barabási, 2000). Entrainment is a process that leads to temporal coordination of two actors' behaviour, in particular, synchronization, even in the absence of a direct mechanical coupling. In dynamical systems research interpersonal entrainment is often considered as a particular instance of the coupling of rhythmic oscillators (Schmidt & Richardson, 2008) that is frequently observed in mechanical as well as biological systems.

### *Common Affordances*

Whereas entrainment occurs in the direct interaction between agents, common object affordances provide the basis for a further dynamical process of emergent coordination. Object affordances (Gibson, 1977), previously discussed as the 'funktionale Toenung' of objects (von Uexkuell, 1920), specify the action opportunities that an object provides for an agent with a particular action repertoire. For instance a chair 'invites' sitting down on it.

When two agents have similar action repertoires and perceive the same object, they are likely to engage in similar actions because the object affords the same action for both of them. This is a type of affordance that we will call common affordance because it leads to emergent coordination when agents perceive the same objects at the same time. Examples for of objects with a common affordance that may induce emergent coordination include the arrival of a bus, an apple falling from a tree, and a shelter in the park. Another case of affordance, which we call joint affordance, is where objects have an affordance for two or more people collectively which is not necessarily an affordance for any of them individually. For example a long two-handled saw affords cutting for two people acting together.

*Perception action matching: Common action representations*

A third process that can lead to emergent coordination is the matching of observed actions onto the observer's own action repertoire. Such a matching can lead to mimicry of observed actions because perceiving a particular action activates corresponding representations that also guide the actions of the observer. Common representations in perception and action have been postulated in extensions (Hommel, Muesseler, Aschersleben, & Prinz, 2001; Jeannerod, 1999; Prinz, 1997) of ideomotor theories of voluntary action control (James, 1890) and have received neurophysiological support from single-cell studies in monkeys and brain imaging studies in humans (Rizzolatti & Sinigaglia, 2010). In monkeys and humans the matching is based on the similarity in actor-object relations. For instance, seeing someone grasp a grape activates grasping actions directed at small, round objects. In humans, the matching can also be based on similarity in intransitive movements that are not directed at objects. For instance, observing someone dancing will activate corresponding action representations if one knows how to dance (Calvo-Merino, Glaser, Cross, Grèzes, Passingham, & Haggard, 2005; Cross, Hamilton, & Grafton, 2006). The perception action match can lead to emergent coordination

because it induces the same action tendencies in different agents who observe each other's actions (Knoblich & Sebanz, 2008).

*Action simulation: Common predictive models*

The fourth process of emergent coordination is closely related to the perception action matching described above. Once a match between observed and performed actions is established it enables the observer to apply predictive models in his or her motor system to accurately predict the timing and outcomes of observed actions. This process is often referred to as action simulation (Sebanz & Knoblich, 2009) because it uses internal models guiding an agent's own actions to predict other agents' actions in real time (Wolpert, Doya, & Kawato, 2003). To illustrate, a basketball player observing a shot will be able to accurately predict whether the shot will be a hit or a miss (Aglioti, Cesari, & Romani, & Urgesi, 2008). Action simulation can lead to emergent coordination because it induces the same expectations about the unfolding of actions in different actors and thus induces similar action tendencies for future actions (Knoblich & Sebanz, 2008).

This concludes our preliminary outline of four sources of emergent coordination. In the next main section we present evidence for the existence of emergent coordination generally and for its occurrence in the context of joint action more specifically, and we discuss hypotheses about the positive consequences of emergent coordination for joint action. First we turn to planned coordination which, unlike emergent coordination, depends on representing the outcomes of joint actions and individuals' contributions to them.



## 2.2 Planned coordination

In order to perform joint actions, such as playing a piano duet or lifting a heavy log, planned coordination is usually required. In planned coordination agents plan their own actions in relation to joint action outcomes or in relation to others' actions whereas planning is absent or confined to the agent's own actions in emergent coordination. The extent to which other agents' tasks, perceptions, and knowledge are taken into account during planning of joint actions may vary greatly. Minimally, planned coordination requires a plan that specifies the joint action outcome, one's own part in a joint action and some awareness that the outcome can only be brought about with the support of another agent or force (X). For the minimal joint action plan, the identity of X and its part in the joint action can remain unspecified as captured by the formula 'ME + X' (Vesper et al., in press). Starting with minimal representational requirements (Clark, 1997) allows one to address a wide range of joint actions (Tollefsen, 2005) that do not involve the detailed representation of other agents or their plans that have been postulated in philosophical approaches to joint action (Bratman, 1992; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Given our focus on the nuts and bolts of joint action assuming such detailed representations seem unnecessarily restrictive. Among the many processes contributing to planned coordination we will focus on joint task representations and joint perceptions.

### *Joint task representations*

In the minimal cases of joint action, actors represent an outcome that they are not going to achieve alone and the task they need to perform themselves. Very often, though, joint action involves representations of the other agents who are actually and potentially involved. For

instance, a chimpanzee who can only get food from a tray with the help of a con-specific may select one among several potential helpers according to how useful each is likely to be (Melis, Hare, & Tomasello, 2006). This chimpanzee needs to represent the goal of obtaining food and their own task of pulling a rope but need not have detailed representations of the con-specific's actions. Often, however, representations of others' tasks are more detailed, specifying the actions others are going to perform. This is demonstrated by children's (Carpenter, 2009) and adults' proneness to represent specifics of others' actions and tasks (Sebanz, Knoblich, & Prinz, 2005).

Joint task representations provide control structures that allow agents to flexibly engage in joint action. Joint task representations not only specify in advance the individual parts each agent (me and you in the simplest case) is going to perform but they also govern monitoring and prediction processes that enable interpersonal coordination in real time (Knoblich & Jordan, 2002; Pacherie & Dokic, 2006). For instance, two soccer players of one team, where one player is specialized on crosses and the other is specialized on headers, will monitor and predict each other's running paths in the light of their individual tasks.

### *Joint perceptions*

Planned coordination can be improved by including another's perceptions into one's own representation of the other's task. This can consist in taking the other's perspective in situations where co-actors' perspectives on a jointly perceived environment differ such as when two actors sit face to face looking at objects to be assembled. Or it can consist in inferring what a co-actor can or cannot perceive in situations where perceptual access to objects in the environment differs between co-actors (Brennan & Hanna, 2009; Keysar et al., 2009). Although it is debated how prone agents are to co-representing each other's perceptions, there is evidence that at least some aspects of another's perspective are computed

even when doing so hinders one's own performance (Samson, Apperly, Braithwaite, Andrews, & Bodely Scott, in press). Co-represented perceptions might be highly useful for planned coordination in helping to establish perceptual common ground between actors (Clark, 1996), in enabling one to adapt one's own task, and in facilitating monitoring of the other's task.

### 2.3 Summary

This section distinguished two types of coordination, one—emergent coordination—involving multiple individuals acting in similar ways thanks to common perception-action couplings, and another—planned coordination—involving representations of a joint action goal and contributory tasks to be performed in pursuit of it. Whereas emergent coordination involves processes such as entrainment and perception action matching, planned coordination is supported by joint task representations and joint perceptions. In what follows we review evidence for the existence of the various processes and structures we have linked to each type of coordination. Because much of this evidence is found outside of joint action, we also examine how these processes and structures facilitate joint action. In the final sub-section we also explore the synergy of emergent and planned coordination.

### 3. Evidence

#### 3.1 Emergent coordination

##### *Entrainment*

For a long time, psychologists (Condon & Ogston, 1966; Trevarthen, 1979) have recognized the importance of rhythmic behaviour in social interaction. Building on this earlier work psychologists subscribing to a dynamical systems view now propose that entrainment is best understood as a self-organizing process that occurs in coupled oscillators (Haken, Kelso, & Bunz, 1985). The claim is that just as two clocks hanging on the same wall tend to synchronize because they are mechanically coupled (Huygens, 1673/1986) individuals may become automatically coupled through perceiving the same visual, auditory, or haptic information. This hypothesis was tested in experiments that determine whether people fall into synchrony even though they try to keep their own speed (Schmidt & O'Brien, 1997). Such experiments provide converging evidence that people cannot resist falling into synchronous behaviour with others.

Schmidt and O'Brien (1997) were perhaps the first to study explicitly whether interpersonal entrainment between two people would occur even when both try to resist entrainment and try to maintain their own speed. In their experiment two persons sitting side by side moved a hand held pendulum. One person used her left hand and the other person used her right hand so that the two pendulums were located in between the two persons. On each trial both individuals started out moving their own pendulum in a speed that felt comfortable to them. Importantly, they were asked to look straight and thus did not see each other or the pendulums during this phase. For the second half of each trial both individuals were asked to "maintain their preferred tempo from the first half of the trial while looking at the other participant's moving pendulum" (Schmidt & O'Brien, 1997).

Two results showed that participants could not resist falling into synchrony with each other. First, cross-spectral coherence, a sensitive measure of the correlation between the timing of the two individual movements, was higher during the second half of the trial than during the first half of the trial. Second, the relative phase between the two movements was much more frequently close to  $0^\circ$  and  $180^\circ$  during the second half of the trial than during the first half of the trial. Especially the later result shows that the two individuals could not resist falling into synchrony, either in-phase ( $0^\circ$ , same synchronized turning points for the pendulum) or anti-phase ( $180^\circ$ , different synchronized turning points for the pendulum).

Richardson and colleagues (2007, Experiment 2) obtained further evidence to support this claim. They asked two individuals to rock in a rocking chair at their preferred tempos either while looking at each other or while looking away from each other. The results demonstrated that individuals could not resist interpersonal entrainment even if the ‘natural rocking frequencies’ (eigenfrequencies) of the two rocking chairs they were rocking in differed. Unlike in the pendulum studies participants were only drawn into in-phase coordination (same synchronized turning front and back) and not into anti-phase coordination suggesting that interpersonal entrainment varies depending on the specific body parts and the specific objects being moved.

A further recent study (Oullier, deGuzman, Jantzen, Lagarde, & Kelso, 2008) investigated whether effects of unintended coordination occur for tapping movements. Two individuals were instructed to tap a comfortable tempo with a finger. As in the previously described experiments they were either looking at each other’s tapping movements or had their eyes closed. Auditory signals indicated when participants should open or close their eyes. Again, the analysis of relative phase revealed that participants strongly tended to fall into synchrony (in-phase only). Surprisingly, two participants stayed entrained with each other even when they closed their eyes again after having seen each other’s movements. This

finding conflicts with the view that interpersonal entrainment can be reduced to a coupling between oscillators because this would predict that each individual should return to their preferred tempo. Accordingly, Oullier et al. (2008) propose that a ‘social memory’ keeps participants synchronized when the visual input supporting the coupling is absent.

Tognoli and colleagues (2007) adapted the tapping task described above to investigate whether there are specific neural markers of interpersonal entrainment in the human electroencephalogram (EEG). In particular, they simultaneously recorded EEG from two people who were looking or not looking at each other’s tapping (see above). The results demonstrated that two oscillatory EEG components in the range between 10 and 11 Hz, Phi1 and Phi2, specifically occur during interpersonal entrainment. Whereas Phi1 activation decreased with increasing coordination Phi2 activation increased with increasing coordination. It remains to be seen whether Phi1 and Phi2 can be established as a general marker of interpersonal entrainment across different experimental settings.

Issartel, Marin, & Cadopi, (2007) demonstrated that behavioural effects of interpersonal entrainment can even be obtained when participants are asked to freely move their forearms while explicitly instructed to ignore each other’s peripherally observed movements. Although under this instruction participants did not engage in the joint rhythmic movements characterizing the studies above, their individual motor signatures (preferred movement frequencies) became more similar when they peripherally observed each other’s movements. This demonstrates that individuals cannot resist subtle interpersonal entrainment effects for ‘freely chosen’ movements that look random and independent to an observer.

Harrison & Richardson (2010) investigated whether the same principles govern the rhythmic movement of four limbs within and across organisms (Jeka, Kelso, & Kiemel, 1993). Two participants were asked to walk around at a certain distance from one another. The participant walking behind could either see the other participant or was mechanically

connected to the participant by a big foam cube, or both. The results showed that when the two participants were only visually or mechanically coupled they fell into a coordinated walking pattern that very much resembled a horse pace. When they were visually and mechanically coupled they fell into a walking pattern that very much resembled a horse trot. These findings suggest that the same stable multi-limb coordination patterns can emerge within and across organisms (cf. Mechsner & Knoblich, 2004).

Finally, the mechanisms of interpersonal entrainment have also been investigated in situations that involve more than two persons. One famous example concerns the dynamics of the transformation of tumultuous applause into orderly and rhythmic clapping studied by Nédá, and colleagues (2000). They demonstrated that applauding audiences fall into synchrony by slowing down their own spontaneous clapping to roughly half its initial speed. Interestingly, the slower tempo required for synchronization of large groups considerably reduces the loudness of the applause so that synchronization disappears again to increase noise levels.

### *Affordance*

Whereas the studies described above provide ample evidence for interpersonal entrainment, the role of affordances as a mechanism for emergent coordination has so far not been addressed (Knoblich & Sebanz, 2008). Although object affordances have been studied extensively in experiments on individual perception (Jones 2003; Tucker & Ellis, 1998, Yoon, Humphreys, & Riddoch, in press), we are not aware of psychological experiments addressing the role of affordances in emergent coordination. Such experiments would need to establish that similar action affordances induced by ‘usable’ objects help actors to coordinate their actions. Such benefits should be particularly strong when actors have the same experience with the particular use of objects because coordination should profit from the increased

similarity in actor-object relations that results from frequently using objects in the same way. Some researchers have started to explore how the presence of another person creates affordances for acting together (Richardson, Marsh, & Baron, 2007). This reflects an interaction between planned and emergent coordination and will be discussed below.

### *Perception action matching*

Perception action matching is a further mechanism that can lead to emergent coordination. Whereas processes of entrainment can explain why two actors' rhythmic actions get aligned, perception action matching can explain why individuals tend to perform similar actions (Brass & Heyes, 2005) or actions that lead to similar perceptual consequences (Hommel et al., 2001; Prinz, 1997) while observing each other. Accordingly, studies on entrainment tend to address situations where people perform the same or very similar movements (but see Richardson, Campbell, & Schmidt, in press). However, visual and auditory entrainment should occur regardless of action similarity if two actions are performed at the same frequencies. The studies on perception action matching, mimicry, and action simulation described below tend to exclusively focus on the similarity between observed actions and performed actions and neglect the role of timing.

Several studies have demonstrated that observing a particular movement in another person leads to an automatic activation of the same movement in the observer (Brass, Bekkering, & Prinz, 2001; Bertenthal, Longo, & Kosobud, 2006). In Brass and colleagues' (2001) experiment participants observed a video of either a lifting movement or a tapping movement on the computer screen. In one block, participants were instructed to respond to any movement on the screen with a tapping movement. In a second block participants were instructed to respond to any movement on the screen with a lifting movement. Although participants knew exactly what to do in each trial participants were faster performing a lifting



movement when they observed a lifting movement and faster performing a tapping movement when they observed a tapping movement.

Stuermer, Aschersleben, and Prinz (2000) found similar results for manual movements. Participants observed videos of a hand that performed a spreading movement or a grasping movement from a neutral position. They were instructed to react to a colour patch that occurred at the same time as the movement onset or shortly after movement onset. For one colour the response consisted in a spreading movement and for the other colour the response consisted in a grasping movement. Thus the observed hand movement was irrelevant for the response. Nevertheless, responses were faster when they corresponded to the observed movement providing further evidence for the assumption that observing a movement activates the same movement in the observer's motor repertoire.

In another study, Kilner, Paulignan, and Blakemore (2003) asked participants to perform vertical or horizontal arm movements while observing vertical or horizontal movements of a human actor or of a robot. They found that the participants' arm movements became more variable if they did not correspond with the observed human movement than when they corresponded with the observed human movement. The correspondence effect was not present when robot movements were observed. This finding suggests that perception action matching occurs only if the kinematics of an observed movement are similar to the kinematics the observer would produce. Richardson, Campbell, & Schmidt (2009) have proposed an alternative explanation for this finding that is based on entrainment mechanisms.

The studies described so far all involved simple movements that were not directed at objects. However, in animal research, the paradigmatic case for a close perception action match consists in movements that serve to manipulate objects (Rizzolatti & Sinigaglia, 2010). Thus several studies have investigated whether a perception action match occurs when an observer perceives another person performing object-directed actions. Castiello and

colleagues (2002) performed a study where participants observed a person grasping a small or a large object and were subsequently asked to grasp a small or large object themselves. If participants performed the same action they had observed before they were faster in initiating their action and more effective in optimizing motor parameters such a grip aperture (see also Edwards, Humphreys, & Castiello, 2003). Similarly, Bach and Tipper (2007) found that observing a person kicking a ball facilitated foot responses whereas observing a person typing on a keyboard facilitated finger responses. Griffiths and Tipper (2009) demonstrated that an observer does not only match the type of action observed but also specific kinematic parameters an observed actor adopts to avoid obstacles to reaching (Jax & Rosenbaum, 2007; van der Wel, Fleckenstein, Jax, & Rosenbaum, 2007).

#### *Action simulation*

Further studies have demonstrated that perception action matching can induce motor predictions in the observer (Hamilton, Wolpert, & Frith, 2004; Wilson & Knoblich, 2005; Wolpert, Doya, & Kawato, 2003). This has been tested varying the similarity between observed actions and the observer's action repertoire. Assuming that this similarity is higher when people perceive their own previous actions than when people perceive somebody else's previous actions Knoblich and Flach (2001) hypothesized that people should be better able to predict the landing position of a dart when observing their own throwing movement than when observing somebody else's movement. The results confirmed the prediction and supported the assumption that perception action matching can trigger motor predictions in the observer (see Knoblich, Seigerschmidt, Flach, & Prinz, 2002, for similar results in the handwriting domain). Converging evidence for this conclusion has been obtained in a study that compared professional basketball players' and basketball reporters' ability to predict the outcome of basketball shots (Aglioti et al., 2008). The hypothesis in this study was that

basketball players' expertise would allow them to more accurately predict whether a particular throwing movement would be a hit or miss and this hypothesis was confirmed.

Finally, it has been demonstrated that perception action matching can influence attention. A study by Flanagan and Johansson (2003) demonstrates that perception action matching can result in predictive eye movements implying that an observer allocates attention to location or objects that the observed actor is expected to manipulate next. Flanagan and Johansson recorded eye movements of a person who moved a stack of objects from one location to another and compared them to the eye movements of people who observed a video recording of these actions. The results showed that the gaze behaviour of participants observing the performance were highly similar to the gaze behaviour of the person who had carried out the original action. These results suggest that perception action matching does not only activate corresponding hand actions in the observer but also mimics processes of eye-hand coordination in the observed actor, in particular, the well known temporal order 'eye precedes hand'.

Findings on inhibition of return across people show that perception action matching can induce inhibition of return mechanisms for locations an observed actor attended to (Welsh et al., 2005). Inhibition of return refers to the phenomenon that it takes individuals more time to detect a target when it appears in the same location as another stimulus presented shortly before the target. Welsh and colleagues (2005; 2007) demonstrated that observing a person respond to a target in a particular location slowed down an observer's response to a target appearing at the same location. This between-person inhibition of return effect suggests that inhibitory attention processes can be triggered by mere action observation. The results of a recent study by Frischen, Loach, and Tipper (2009) also support this conclusion. This study demonstrated that observing another's actions triggered inhibitory attention processes of

negative priming. Interestingly, in the observation condition the inhibitory processes followed the observed actor's spatial reference frame and not the observer's spatial reference frame.

Overall, then, there is a rich body of evidence for three sources of emergent coordination and an open question about a fourth source, common affordances. Note that the evidence we have reviewed so far mainly concerns non-joint action situations where participants were not instructed to act together and where coordination among agents was not beneficial to performing the task and in some cases may have degraded performance. This raises two questions. First, what evidence is there that emergent coordination occurs when agents are performing a joint action? Second, how (if at all) could emergent coordination facilitate joint action? We now address these questions in turn.

### 3.2 Emergent coordination during joint action

In the studies reviewed in the previous section emergent coordination occurred despite the fact that individuals were instructed to ignore each other's actions or at least were not given reason to attend to each other. This section reviews studies where emergent coordination was studied in the context of joint action including conversation. In all of these studies, two individuals showed emergent coordination of behaviour that was apparently not necessary for achieving the goal of the joint action. This includes emergent coordination of movements such as body sway (Fowler, Richardson, Marsh, & Shockley, 2008) as well as emergent coordination of eye movements between speaker and listener in a conversation (Richardson, Dale, & Shockley, 2008).

#### *Entrainment*

Although temporal coordination of speech patterns and body movements during conversation have been the subject of many observational studies (Condon, 1976; Kendon, 1970;

Wachsmuth, Lenzen, & Knoblich, 2008), the systematic experimental study of interpersonal entrainment during joint action and conversation is quite new. Richardson, Marsh, and Schmidt (2005) investigated interpersonal coordination of pendulum swinging while participants solved a puzzle task. Participants were asked to swing hand held pendulums while jointly solving the puzzle. Two factors were varied: Participants either saw or did not see each other and they either talked or did not talk to each other. Interpersonal entrainment occurred only when participants perceived each other's movements, implying that verbal interaction alone was not sufficient to produce a coupling between the individuals. However, the lack of interpersonal entrainment in the verbal interaction condition may be due to the dual task character of the study. Rhythmic pendulum movements and verbal rhythms may not have been sufficiently related to produce an interpersonal entrainment of manual movements through speech.

Studies on interpersonal entrainment of body sway during conversation suggest that talking to each other can indeed be sufficient to produce interpersonal entrainment of body sway (Fowler et al., 2008), which consists in automatic movements that serve to keep a stable body posture. Shockley and colleagues (2003) asked two individuals to find subtle differences between two cartoon pictures either of which could only be seen by one of them. Participants were either facing each other or looking away from each other. The surprising finding was that talking to each other was sufficient to create interpersonal entrainment of body sway, as evidenced by a higher rate of recurrence in a cross-recurrence analysis (this analysis allows one to discover similarities in temporal patterns across different time series (Shockley, Butwill, Zbilut, and Webber, 2002). In a recent study Shockley, Baker, Richardson and Fowler (2007) extended these results by showing that particular properties of the conversation such as dyadic speaking rate and similarity in stress patterns give rise to acoustically mediated entrainment of body sway. Stoffregen, Givens, Villard, Yank, and Shockley (2009) have

identified further factors that modulate the entrainment of body sway such as the rigidity of the surface people are standing on.

However, body sway is not the only type of movement that gets entrained during conversation. Two studies demonstrated that there is also acoustically mediated emergent coordination between the eye movements of speakers and listeners. Richardson and Dale (2005) recorded eye movements from speakers describing stories from an American sitcom they were highly familiar with while looking at the main characters. The verbal utterances were replayed to listeners (new participants) who were also familiar with the same sitcom while their eye movements on the same display of the main characters were recorded. Cross-recurrence analysis was used to determine overlap in the temporal patterns of speaker and listener. This analysis showed that verbal utterances were sufficient to produce emergent coordination between the eye movements of the speaker and the listener. In other words, verbal communication led to an overlap in the temporal rhythm between a speaker and a listener thereby aligning attention. Similar results were obtained in a setting where speaker and listener were engaged in a real time dialogue (Richardson, Dale, & Kirkham, 2007).

### *Perception action matching*

Studies on non-conscious mimicry during dialogue have also revealed emergent coordination based on perception-action matching. These studies demonstrate that observing the actions and mannerisms of a conversation partner leads individuals to perform the same movements without being aware of mimicking their partner. Chartrand and Bargh (1999) provided a demonstration of this ‘chameleon effect’ by asking participants to take turns with another participant sitting next to them at describing photographs. The other participant was actually a confederate who engaged in particular mannerisms such as shaking her foot or rubbing her face. Video analyses showed that participants mimicked the confederate, rubbing their face

more often when the confederate rubbed her face and shaking their foot when they observed their partner shaking her foot. Participants were not aware of their partner's mannerisms and did not deliberately try to mimic them. This suggests that perceiving an action triggers corresponding action representations in the observer, which can lead to overt mimicry in the context of conversation. The extent to which people mimic others' actions depends on individual characteristics, including the tendency to take others' perspective (Chartrand & Bargh, 1999), and the tendency to rely on contextual information and to feel close to others (for a review see van Baaren, Janssen, Chartrand, & Dijksterhuis, 2009).

### 3.3 Consequences of emergent coordination

We have just seen that emergent coordination occurs in joint action contexts, for example when two people are solving a puzzle together. But in the studies cited so far, emergent coordination appears to occur independently of participants' individual and shared goals. As noted, emergent coordination may sometimes even interfere with individual action planning as when people can't help falling into the same rhythm or mimicking observed actions. This may seem puzzling if, as we have proposed, emergent coordination can facilitate some joint actions. In fact several recent studies suggest that emergent coordination has various effects that may serve a number of different psychological functions. These effects include increased affiliation and liking of a partner, increased willingness to cooperate with the partner, and increased understanding of the meanings a partner intends to convey in a conversation.

#### *Entrainment*

It has long been suggested that the rapport between individuals is reflected in the synchrony of their body movements (e.g., Bernieri, 1988). More recently, Miles, Nind, and Macrae

(2009) demonstrated that people judge the connectedness of individuals in a dyad based on the perceived synchrony of their movements. Participants saw or heard footsteps of pairs of walkers walking in a more or less synchronized manner, and rated their degree of rapport. The results showed that participants attributed the highest levels of rapport to those pairs of walkers that displayed in-phase or anti-phase coordination, and assigned the lowest levels of rapport to walkers displaying phase relationships that were far from in-phase or anti-phase. Thus, the most stable patterns of entrainment were clearly perceived as reflecting a close connection between individuals, regardless of whether information about the walkers' synchrony was conveyed through visual or auditory information.

That observers take synchrony to indicate rapport does not establish that these are causally related. Evidence for a causal link has been provided by Hove and Risen (2009). In their study participants performed a tapping task next to another person, synchronizing their finger movement with a visual or auditory signal. Each of the two individuals responded to separate signals so that the target tempo for their tapping could be more or less similar. Even though participants knew that the signals determined to which extent they and their task partner were synchronized, those who had been more in synchrony with their partner subsequently reported liking her more.

Entrainment also seems to boost people's willingness to cooperate with group members (Wiltermuth & Heath, 2009). In a coordination game participants who had walked in step in groups of three made more cooperative choices than participants who had not walked in step. Those who had engaged in synchronized walking also reported feeling more connected and trusting each other more. The same was true for groups of three singing in synchrony. Of particular interest was the further finding, using multiple rounds of a public-goods game, that following synchronous group actions, the level of participants' contributions to the public good did not significantly fall as time went by, whereas the level of such



contributions did decline over time in groups that had not engaged in synchronous behaviour. These findings suggest that by increasing group cohesion, synchronous group action serves to increase altruistic behaviour.

Improvements in joint action performance following entrainment, as well as gains in understanding due to entrainment during conversation, provide further demonstrations of the benefits of entrainment. In a study by Valdesolo, Ouyang and DeSteno (2010), two groups of participants rocked in rocking chairs. One group rocked next to each other, which allowed them to entrain, while the other group rocked back to back to avoid entrainment. Participants who had rocked in synchrony were subsequently better at an individually performed perceptual sensitivity task that required judging the speed of an occluded object, compared to participants who had rocked back to back. Interestingly, the increased perceptual sensitivity induced by the synchronized rocking may explain why synchronized dyads also performed better in a subsequent joint action task that involved steering a ball through a labyrinth together. These findings provide a first indication that entrainment may have effects on the quality of subsequent joint action performance.

The study by Richardson and Dale (2005) discussed above provides evidence that emergent coordination between the eye movements of a speaker and listener can aid understanding. In their experiments, a speaker monologued while looking at an array of six characters; listeners then saw the same display (but not the speaker) while hearing the monologue. The degree to which the gaze between speakers and listeners overlapped predicted how many comprehension questions listeners subsequently answered correctly. A second experiment provided evidence that gaze coordination and comprehension are causally connected. While looking at array of characters, listeners' attention was drawn to particular locations at particular times by having the pictures of the characters flash. This made it possible to make listeners' gaze pattern more or less similar to the speaker's. Compared to a

condition where the flashes appeared at shuffled times, participants indeed responded to comprehension questions more readily when their gaze had been drawn to the locations coinciding with the speaker's gaze fixations.

### *Perception action matching*

Increased liking seems to result not only from entrainment, but also from non-conscious mimicry, the tendency to perform the same actions as one's interaction partner without being aware of doing so. The classic study on the "chameleon effect" (Chartrand & Bargh, 1999) included an experiment where the confederate either mimicked participants' postures, movements, and mannerisms without them being aware of it, or simply sat next to them in a relaxed position. Participants who had been mimicked reported liking the confederate more and judged the interaction as smoother, suggesting that nonconscious mimicry may act as a kind of 'social glue' (Lakin, Jefferis, Cheng, & Chartrand, 2003). Many studies have since confirmed and extended this finding (for a review, see van Baaren et al., 2009).

In particular, being mimicked does not only lead to increased liking of the person who did the mimicking, but seems to increase people's pro-social orientation in general (van Baaren, Holland, Kawakami, & van Knippenberg, 2004). Participants whose postures had been mimicked were more likely to help pick up pens dropped by a stranger and donated more money to a charity. A further study by van Baaren and colleagues also suggests that mimicry increases the tendency to share resources. They demonstrated that when a waitress mimicked her customers, they gave her significantly larger tips (van Baaren, Holland, Steenaert, & van Knippenberg, 2003).

So far in this section we have surveyed basic evidence for four sources of emergent coordination and reviewed evidence that emergent coordination occurs in the context of joint action. As we saw, there is evidence that two sources of emergent coordination, entrainment

and perception action matching, occur when people are acting together and, in particular, when they are engaged in conversation. The mere fact that emergent coordination occurs in joint action does not show, of course, that it plays any role in facilitating it. In fact, we saw that in some cases emergent coordination may make performing joint actions harder than it would otherwise be. A crucial question, then, is how emergent coordination facilitates joint action. We have already seen part of the answer: emergent coordination promotes rapport and willingness to contribute to a group, which may indirectly benefit joint action; more directly, emergent coordination in the form of spatio-temporally coincident gaze appears to facilitate understanding. This evidence is consistent with a range of possible views on significance of emergent coordination for joint action. Our own conjecture, supported below, is that emergent coordination cannot be fully understood in isolation from planned coordination. For many of the ways in which emergent coordination enables effective joint action depend on it functioning in combination with planned coordination. Before developing this theme we first consider evidence for planned coordination at length.

### 3.4 Planned coordination

#### *Joint task representations*

In prototypical cases of planned coordination agents represent an outcome to be achieved, their own task, and some aspects of other agents' tasks in achieving that outcome.

Psychological experiments performed with the aim of investigating how individual task performance is modulated by co-actors' tasks have shed light on the question of when and how others' tasks are represented. Although representing a co-actor's task may not always be necessary, the findings of these experiments consistently suggest that humans form task representations that specify not only their own part, but also the part to be performed by the

co-actor. Moreover, the findings suggest that task representations entailing a specification of the individual tasks each agent is going to perform govern stimulus processing (Heed, Habets, Sebanz, & Knoblich, in press), action monitoring (Schuch & Tipper, 2007), control (Sebanz, Knoblich, Prinz, & Wascher, 2006; Tsai, Kuo, Jing, Hung, Tzeng, 2006) and prediction (Ramnani & Miall, 2004) processes during the ensuing interaction.

A first study (Sebanz, Knoblich, & Prinz, 2003) investigated whether a response selection conflict between two action alternatives (a right and a left button press) that is known to occur within individuals is also observed across individuals in a social setting. Participants responded to pictures of a red or green ring presented on an index finger pointing left or right. When participants performed the two-choice task alone, they responded to red stimuli by pressing a left button and to green stimuli by pressing a right button. Although the pointing direction of the index finger was irrelevant, participants responded faster to red stimuli when the finger pointed left than when it pointed right, and vice versa for green stimuli. This spatial compatibility effect demonstrates that the irrelevant spatial information of the stimulus elicited a response conflict when the finger pointed to the side opposite to the button that had to be pressed.

The social version of this task tested whether the same response conflict would occur across individuals where neither individual's task required taking the co-actor's actions or task into account. One participant responded to red stimuli by pressing a single button in front of her. Next to this participant sat another participant responding only to green stimuli with her own button. Thus, each task could be performed without taking the co-actor's task into account. Nevertheless, a response selection conflict was observed, with participants responding more slowly when the finger pointed at their co-actor. A control condition showed that this interference did not occur when another person merely sat next to participants. The findings of this first study suggest that participants did not ignore their co-actor. Instead, they

represented the action to be executed by the co-actor so that a similar conflict in action selection occurred regardless of whether they were in charge of both actions or whether they performed the task together.

These findings were replicated in a study where participants responded to odd and even numbers with left or right key presses (Atmaca, Sebanz, Prinz, & Knoblich, 2008). The numbers ranged from two to nine and number magnitude was always irrelevant. It is well established that when individuals perform the parity task alone, as a two-choice task, left key presses are faster in response to small numbers and right key presses are faster for large numbers. This effect of number magnitude on parity judgments (the so-called ‘SNARC’ effect) has been explained by the assumption that the perception of numbers automatically activates a magnitude representation on a mental number line going from the left to the right (Dehaene, 1997). Atmaca and colleagues showed that the same effect occurs when two people sitting next to each other perform the task together, so that one responds only to even numbers and the other only to odd numbers. Participants sitting on the left were faster when responding to small numbers, and participants sitting on the right were faster when responding to larger numbers. This suggests that, as in the compatibility task described above, participants represented their own action alternative in relation to the co-actor’s actions.

These findings on task co-representation have raised many questions. In particular, there has been considerable debate regarding the mechanisms underlying the observed co-representation effects. Guagnano and colleagues (Guagnano, Rusconi, & Umiltà, in press) tested whether co-representation effects only occur when two actors perform complementary tasks, taking turns in responding, or whether co-representation effects occur even when the two agents’ tasks are completely independent. In their study, the two participants in a pair performed independent detection tasks, one responding to red stimuli and the other to blue stimuli. The stimuli appeared either on the side on which the response should be made

(compatible) or on the opposite side (incompatible). On 80% of the trials the stimuli required a response from both participants to avoid turn taking and to make the two tasks maximally independent.

A compatibility effect was observed when the two participants were sitting close to each other, within arm reach (in so-called peripersonal space). However, the compatibility effect vanished when the co-actors were sitting outside of each other's peripersonal space. Based on these findings, Guagnano and colleagues suggested that if a co-actor is sufficiently close, the co-actor provides a spatial reference point for coding the location of one's own action. Instead of representing the specifics of the other's task, then, co-actors might simply use the other as a spatial reference. However, it remains to be specified how exactly such a spatial reference is established. Welsh (2009) reported similar compatibility effects when participants sitting next to each other crossed their hands and when they performed the same tasks with hands uncrossed. This finding suggests that if spatial coding is taking place, it can be flexibly based on the position of one's body relative to the other's body, or on the position of one's hand relative to the other's hand.

A recent study (Heed, Habets, Sebanz, & Knoblich, 2010) demonstrates that both the spatial relation between co-actors and task representations specifying the co-actor's part play a role. In this study, participants held cubes that emitted tactile stimulation on top (index finger) or at the bottom (thumb). Their task was to indicate via a foot response at which location the tactile stimulation had occurred. A light appeared on top or at the bottom of the cube (congruent or incongruent with the tactile stimulation) and was irrelevant for the task. When participants performed this task alone, responses to tactile stimuli were faster when the irrelevant light appeared in the same location (e.g., touch and light at the bottom) compared to when the light and the tactile stimulation appeared in opposite locations (e.g., touch at the bottom, light on top, Spence, Pavani, Maravita, & Holmes, 2004). Heed and colleagues tested

whether this cross-modal congruency effect is modulated when a co-actor performs a task involving the lights.

Based on earlier findings on joint task representations, one might predict stronger cross-modal interference because the irrelevant lights are relevant for one's task partner. However, representing the other's task could also facilitate task performance given that, unlike in previous studies, stimuli from two different sensory modalities were distributed between two co-actors. The results indeed showed that the person responding to tactile stimuli could ignore the irrelevant light much better when her co-actor responded to the location of the light. This effect only occurred, however, when the person responding to lights was sitting in the peripersonal space of the person responding to tactile stimuli, and when she responded to all lights. The reduction in cross-modal congruency was not observed when the person in charge of lights responded only to one of two different coloured lights. This finding indicates that the weight assigned to the visual modality was changed when the partner's task covered all visual events in peripersonal space. Thus, a representation of the other's task modulated stimulus processing provided that the co-actors were in a particular spatial relation to each other.

Stimulating further debate about the mechanisms underlying joint task representations, some studies indicate that for others' actions to be included in one's own action plan, they must be visible (Welsh, Higgings, Ray, & Weeks, 2007) and of a biological nature (Tsai & Brass, 2007), whereas other findings suggest that co-representation occurs even when people merely believe that they are acting together with another person (Ruys & Aarts, in press; Tsai, Kuo, Hung, & Tzeng, 2008). Using the social compatibility task described at the beginning of this section, Tsai and colleagues (2008) told participants that they were going to perform the task (e.g., responding to red stimuli) together with a person in another room (responding to green stimuli) or with a computer program (the computer taking care of green stimuli). They

found a compatibility effect when people believed that they were performing the task together with another person but not when they believed that they were performing the task with the computer. This indicates that the actual task performance is constrained by task representations formed in advance. Importantly, in the studies that found co-representation effects with invisible co-actors, participants constantly received (mock) feedback about the other's actions (Ruys & Aarts, in press; Tsai et al., 2008). This feedback may be necessary to maintain a representation of the other's task.

Electrophysiological and brain imaging methods have been used specifically to investigate the processes occurring when a co-actor does not need to act herself and awaits the other's response. These studies have revealed two main findings. First, individuals seem to generate predictions of the other's actions based on their representation of the other's task (Ramnani & Miall, 2004). For instance, if two participants have been instructed to perform particular actions in response to certain colour cues, seeing a colour cue that specifies the action to be performed by a co-actor elicits activation in brain areas associated with mental state attribution, which may reflect an ongoing prediction process.

Second, electrophysiological evidence suggests that acting together requires the recruitment of control processes to ensure that one does not act when it is the other's turn. A positive event-related potential occurring 300-500ms post-stimulus was significantly more pronounced when participants needed to inhibit an action because it was their co-actor's turn compared to when they needed to inhibit an action because it was nobody's turn to act (De Bruin, Miedl, & Bekkering, 2008; Sebanz, Knoblich, Prinz, & Wascher, 2006; Tsai, Kuo, Jing, Hung, Tzeng, 2006).

Effects of joint task representations on action control have also been demonstrated by studies investigating the observation of errors (Bates, Patel, & Liddle, 2005; Schuch & Tipper, 2007; van Schie, Mars, Coles, & Bekkering, 2004). To investigate whether similar



inhibitory processes occur in the person trying to stop an action and in an observer watching her co-actor stop an action, Schuch and Tipper asked participants to respond to targets as quickly as possible, but to stop if a stop signal was presented shortly after the target. It is well known that participants respond more slowly on the trial following a stop signal, both if they have successfully stopped and if they have made an error. The results showed that participants were not only slower after they had stopped or made an error themselves, but also after their co-actor had done so. This indicates that control processes governing one's own actions are also active during co-actor's performance, even if the co-actor's performance is irrelevant for one's own task.

The study by Ramnani and Miall (2004) mentioned above is also important in that it shows that completely arbitrary task rules are co-represented. In many other co-representation experiments, the stimuli had a spatial dimension, leading to an overlap in perceptual features of the responses to be made by the two co-actors and perceptual features of the stimuli (e.g., Sebanz et al., 2003). In contrast, in the study by Ramnani and Miall, the stimuli did not refer to the co-actors in any such way. This allows one to conclude that co-actors anticipated each other's actions based on their task representation only. Converging results were obtained in a study where participants responded to a spatial stimulus feature next to a co-actor responding to a certain stimulus colour (Sebanz et al., 2005). Whereas some of the stimuli required a response from one participant only, others required a response from both participants. The results showed that participants responding to the spatial stimulus feature were slower when the stimulus colour indicated that it was also the other's turn to respond. This suggests that the (arbitrary) task rule specifying responses to colour was represented by the individuals responding to the spatial stimulus feature.

Recently, researchers have begun to investigate whether and how jointly practiced task rules modulate subsequent performance of another joint task (Milanese, Iani, & Rubichi, in

press). It is known from studies of individual performance that when participants respond to stimuli on the left with a right key press, and to stimuli on the right with a left key press, they subsequently show a reduced or even reversed spatial compatibility effect in a task where they need to respond to colour and have to ignore the spatial position of the stimuli. That is, whereas participants would normally find it easier to make a left key press when a stimulus appears on the left, after the practice, participants find it easier to make a left key press when a stimulus appears on the right.

Milanese and colleagues used this transfer effect to demonstrate that joint practice modulates subsequent joint performance of a compatibility task in just the same way. Interestingly, transfer effects also occurred when participants first performed the practice alone followed by the joint compatibility task, but not when they first performed the practice together, and then performed the compatibility task alone. This indicates that the representations guiding joint task performance may in fact be quite different from the representations guiding individual performance, with transfer occurring more easily from the individual to the joint case. Transfer studies may thus constitute a useful new way to study the nature of joint task representations.

A related line of research has investigated how social factors, such as characteristics of the co-actors and the nature of the interaction context, modulate the tendency to take each other's tasks into account. To investigate possible links between impairments in mental state attribution and co-representation, individuals with autism were asked to perform variants of the spatial compatibility task described above (Sebanz, Knoblich, Stumpf, & Prinz, 2005). They showed similar co-representation effects as a matched control group of typical adolescents and adults, indicating that deficits in understanding particular mental states such as beliefs do not necessarily affect the tendency to represent the rules specifying a co-actor's task. However, recent findings provide a more nuanced view (Ruys & Aarts, in press).

Using an auditory version of the joint compatibility paradigm where participants believed that they were interacting with another person, Ruys and Aarts found that individuals who were good at inferring others' mental states took the co-actor's task into account regardless of the interaction context, whereas individuals who were less able to infer others' mental states showed signs of co-representation only in a competitive context. The ability to infer others' mental states was measured using the mind in the eyes test which requires selecting one of four terms that best describes the emotional state of different pairs of eyes (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001). These results indicate that limitations in the ability to infer others' mental states, which may come with less of a propensity to do so, may also come with a decreased tendency to co-represent others' tasks.

The comparison between competitive and cooperative interaction contexts is of general interest in that it may reveal effects of particular prior intentions on task performance. Such effects have been demonstrated by studies comparing the performance of a grasping movement in a collaborative context, where participants reach for and place a wooden block on a table to build a tower together with a co-actor, and in a competitive context, where participants intend to place the block down sooner than their partner (Georgiou, Becchio, Glover, & Castiello, 2006; Becchio, Sartori, Bulgheroni, & Castiello, 2007). The kinematics differed already during the initial reach-to-grasp action, with longer movement duration, a higher movement path of the wrist, and a later time of opening the hand to grasp (maximum grip aperture) during cooperation than during competition. Control conditions where participants act alone under different instructions suggest that these effects are not simply due to movement speed, but instead reflect the intention underlying the grasping movement.

Finally, affect also seems to play a role in task co-representation. Using the joint compatibility task, Hommel and colleagues (Hommel, Colzato, & van den Wildenberg, 2009) found co-representation effects when participants acted together with a confederate who was

friendly and cooperative, but not when they acted with a confederate who was intimidating and competitive. This result suggests that co-representation only occurs in positive relationships. However, it is also possible that mood is a key factor. When participants were presented with movies to induce a positive, negative, or neutral affective state before performing the joint compatibility task, co-representation effects occurred only following positive and neutral mood induction (Kuhbandner, Pekrun, & Maier, in press).

In short, behavioural, electrophysiological and brain imaging evidence shows that humans represent not only their own tasks but also those of their partners and even those of people who they do not need to coordinate with. Much progress has already been made on questions about when agents represent co-actors[\*\*\*] tasks. As we saw, whether agents represent others' tasks does not appear to depend on whether doing so is necessary for performing their own tasks effectively, nor always on directly perceiving their co-actors; but it does depend on believing that the other task is being performed by an agent rather than an algorithm and in some cases it depends on whether agents are acting in each other's peripersonal space.

While it is difficult at present to specify a detailed model of how joint task representations arise, there is much evidence on the related question of their effects. Representing a co-actor's task means needing to inhibit oneself from performing her actions and having one's motor system become sensitive to her errors. Thus joint task representations influence how agents monitor and plan their actions. In addition, task co-representation may also influence how space is represented and how stimuli are processed. This makes it easy to see how, in general terms, joint task representations could facilitate joint action. By representing their co-actors' tasks, agents are able to coordinate their actions and predict their joint outcome because they are each monitoring and planning both sets of actions.

*Joint perceptions*

Actors can adjust their actions to facilitate coordination if they are able to assess what their partner perceives at a particular moment in time. This may involve directing one's own attention depending on where the other is looking, taking the other's perspective, or inferring what the co-actor can or cannot perceive in situations where perceptual access to objects in the environment differs between co-actors.

A study by Brennan and colleagues demonstrates that co-actors are able to distribute a common search space by directing their attention depending on where the other is looking (Brennan, Chen, Dickinson, Neider, & Zelinsky, 2008). The task was to find the letter 'O' among lots of Qs on a computer screen. Participants were instructed to indicate the presence or absence of the O as quickly as possible by pressing one of two buttons. The two participants in a pair sat in different rooms and wore a head-mounted eye tracker each. This made it possible to indicate the current gaze position of a searcher to her partner, who saw it displayed as a cursor on her screen. Both participants thus could see where their partner was looking. Joint search performance was much better than individual performance. Interestingly, joint performance was best when participants were not allowed to talk to each other. These findings suggest that being able to see where their partner was looking allowed people to divide the search space in an efficient manner.

However, co-actors do not always have access to the same visual input. When they are in different spatial locations, they may have different perspectives on the same scene, and only some objects but not others may be visible to both. There has been considerable debate as to how such differences could be overcome in communication. On the one hand, it has been proposed that people make partner-specific adaptations based on what they assume to be common knowledge (Brennan & Hanna, 2009). On the other hand, it has been argued that

mental state inferences play only a limited role because they are time consuming and cognitively demanding, whereas processes of emergent coordination may be highly useful for achieving coordination (Shintel & Keysar, 2009).

In the light of this debate, recent findings by Samson and colleagues are particularly relevant (Samson et al., in press). Participants were asked to judge their own or another's visual perspective in situations where the two perspectives were the same or different. They found that even when taking the other's perspective interfered with their own task performance because the two perspectives differed, participants computed the other's perspective. This parallels the findings on task co-representation discussed above.

A study on effects of a co-actor's perspective on mental rotation (Boeckler, Knoblich, & Sebanz, under review) provides further evidence that people take another's perspective into account even when this is not required. Participants in a pair sat opposite each other and took turns in performing a mental rotation task with pictures of hands. While one participant performed the task, the participant opposite her either closed her eyes or looked at the pictures. When the co-actor looked at the stimuli to be rotated, participants were slowed down when small rotations were required (large rotations from the other's perspective) and were speeded up when larger rotations were required (smaller rotations from the other's perspective). These findings indicate that the other's perspective could not be ignored. Joint attention triggered a switch to processing the stimuli within the other's, allocentric, reference frame.

### 3.5 The synergy of planned and emergent coordination in enabling effective joint action

Although recent research has enhanced our understanding of the component mechanisms of emergent and planned coordination, it is still not well understood how planned coordination and emergent coordination work together in order to enable effective joint action. However,

numerous studies indicate that planning joint actions taps into several different mechanisms of emergent coordination recruiting the functionality of these fast and parallel mechanisms.

### *Synergy of Planning and Entrainment*

Entrainment is not only observed in situations where individuals do not plan to coordinate with each other but also in situations where individuals plan to coordinate their movements in order to obtain the joint goal of producing a particular movement pattern. Accordingly, proponents of a dynamical systems approach to cognition have stressed the importance of entrainment in planned coordination. In particular, they have studied whether movement coordination across individuals follows the same principles that govern the coordination of limbs within individuals.

Schmidt, Carello, and Turvey (1990) asked two people sitting side by side to rhythmically swing their outer legs (left leg of person sitting on the left and right leg of person sitting on the right) at the same pace as a metronome that indicated different tempos. In the symmetric (in-phase) condition, participants performed synchronous forward and backward movements with their legs, flexing and extending them at the same time. In the parallel (anti-phase) condition participants performed synchronous leg movements but now one participant extended the leg while the other flexed the leg and vice versa.

The main finding was that the dynamical interpersonal coupling between the movements followed several predictions of the HKB equation (Haken et al., 1985) that was originally developed as a quantitative model of inter-limb coordination within a person. In particular, participants found it easier to perform symmetric movements than parallel movements and tended to switch from parallel into symmetric mode, especially at high movement speeds. These results show that the same quantitative relationship holds in planned within-person and across-person coordination of simple rhythmic movements.

Further studies where participants were asked to swing hand held pendulums at different speeds (Schmidt & Turvey, 1994; Schmidt, Beinvenu, Fitzpatrick, & Amazeen, 1998) also support this general conclusion. However, Schmidt and colleagues (1998) noted that planned interpersonal coupling of rhythmic movements was weaker and broke down more easily than across-person coupling of rhythmic movements. This could be an indication that across-person coordination involves mechanisms that are different from the within-person case.

One such difference has been revealed in a recent study on joint tapping where two co-actors overcompensated for each other's timing errors when trying to tap in synchrony with each other (Konvalinka, Vuust, Roepstorff, & Frith, in press). Further evidence that the interpersonal case is special comes from a developmental experiment that investigated drumming in young children. Children aged around 2.5 years deviated more from their preferred drumming tempo when they drummed with an interaction partner than when they drummed with a mechanical device producing the same rhythmic intervals as the interaction partner (Kirschner & Tomasello, 2009). In fact, their drumming in the social interaction condition was in a timing range not spontaneously performed by the children. This indicates that children (and adults) entrain more when they are engaged in social interactions. Thus top-down influences of joint planning may modulate the extent to which entrainment occurs.

Another interesting question with regard to the relation between planning and entrainment is how musicians manage to coordinate rhythmic performances. Goebel and Palmer (2009) investigated which cues pianists use to coordinate their performances. Not surprisingly, visual and auditory feedback was important for synchronization indicating a crucial role for entrainment and online error correction mechanisms (Repp & Keller, 2004). When auditory feedback was absent, pianists produced ostensive cues for each other by finger movements. This indicates that, at crucial points of the musical performance, 'communicative' coordination mechanisms ensure that performers' joint plans stay aligned.



Studies on the entrainment of eye movements between speaker and listener provide further evidence for top-down modulation of the entrainment processes through common knowledge and joint plans. Richardson, Dale, and Kirkham (2007) recorded eye movements from two conversants engaged in a real time dialogue about a Dali painting. Before starting the conversation they either received the same or different information about Dali's art. Cross-recurrence analysis revealed that the eye movements of two speakers who shared common knowledge were more tightly temporally coordinated. In a further study Richardson, Dale, and Tomlinson (2009) demonstrated that the coordination of eye gaze is not only modulated through common knowledge but also by sharing or not sharing a visual scene or believing that the conversation partner has or does not have access to the visual scene.

### *Synergy of Planning and Affordance*

A further interaction between planned and emergent coordination combines joint planning and dynamic actor-object relations (affordances). Perceiving the affordance of an object for oneself (would I be able to lift this object myself?), its affordance for another person (could this person lift this object?), or its affordance for the group (could we lift this object together, given the affordance the object has for me and the other) may provide the basis for deciding whether one should plan an individual action or a joint action. Richardson, Marsh, and Baron (2007, Experiment 4) investigated this hypothesis in an experiment where they asked two individuals to lift planks of different length from a conveyor belt. Participants were free to decide to lift particular planks alone or together and were required to make their decision on the fly as the plank passed by on the conveyor belt.

The results demonstrated that the decision to engage in joint action or individual action systematically depended on the ratio between plank length and the groups' joint arm-span. Moreover, the transition from individual action to joint action followed the same

dynamic principles as the transition from uni-manual to bimanual action in individual plan lifting (Richardson et al., 2007, Experiment 2). Importantly, participants with a longer arm span took into account the shorter arm span of their partner by choosing joint action more frequently than predicted by their individual arm span. Thus the results provide clear evidence that affordances play an important role in deciding whether to perform a joint action or an individual action with an object.

A study by Mottet and colleagues (2001, Experiment 2) provides a further indication that joint action capabilities determine how individuals act in particular task environments. Mottet and colleagues asked participants to jointly perform rhythmical movements as fast as possible. One person moved a pointer in order to move between two targets that varied in size and were separated by different distances. The other person could move the targets making the task easier for the person moving the pointer. The results showed that the combined movements of both persons followed Fitts's law just as when one person performed the whole task bimanually. Fitts's law predicts quantitatively the extent to which increases in target size and decreases in movement amplitude (distance between targets) allow for faster movements between two targets. Thus Mottet and colleagues' study provides evidence that actors can jointly optimize performance to particular object sizes and particular distances between objects.

### *Synergy of Planning and Perception-Action Matching*

Like entrainment, perception-action matching might appear as a low-level process operating largely independently of planned coordination. However, the control of perception-action matching processes is crucial for planned coordination where actors need to perform different actions. There is substantial evidence that higher-level planning processes modulate the matching of perceived actions onto the observer's action repertoire. Attributing particular

intentions to an actor can extinguish the tendency to mimic perceived movements and can trigger the activation of compensatory or complementary movements.

Liepelt, von Cramon, and Brass (2008) showed that the intentions observers attribute to an actor modulate perception-action matching. Participants were instructed to lift either the index finger or the middle finger in response to a number that was presented between the index and middle finger of a picture of a hand. The index or the middle finger of the perceived hand moved up as the number appeared resulting in a congruency effect (slower responses when the finger to be raised in response to the number did not correspond to the perceived finger movement). The key manipulation was whether very small micro-movements of the fingers occurred when a metal clamp restricted the fingers of the perceived hand, or without the clamp, so that the actor was free to move but only performed tiny finger movements anyway. The same movement kinematics led to a larger congruency effect when the fingers of the perceived hand were clamped, giving the impression that the actor was trying hard to move despite her fingers being restricted. Thus, the effect of action perception on action execution changed as a function of the intention attributed to the actor.

The role of intention attribution is also demonstrated clearly by the finding that the same kinematics create more or less interference with action execution depending on whether people believe that the movement of a dot reflects human motion or is generated by a computer (Stanley, Gowen, & Miall, 2007). In an adapted version of the paradigm developed by Kilner et al. (2003), participants performed horizontal or vertical arm movements in time with a dot moving horizontally or vertically. The perceived dot motion interfered with participants' movements when they were told that a person generated the dot motion, but not when they were told that a computer generated the dot motion, regardless of whether the dot actually moved in a biological or non-biological way.

Experiments on ideo-motor movements demonstrate that instead of mimicking perceived actions people tend to make involuntary compensatory movements when they observe actions that are not in line with their own or an observed actor's intentions (De Maeght & Prinz, 2004; Haeberle, Schuetz-Bosbach, Laboissiere, & Prinz, 2008; Knuf, Aschersleben, & Prinz, 2001; Sebanz & Shiffrar, 2007). For instance, participants tracking a ball moving towards a goal on a computer screen moved left when the ball steered too far to the right (De Maeght & Prinz, 2004), even though they had no control over the ball movement. Sebanz and Shiffrar (2007) measured participants' body tilt as they watched someone balancing along a wobbly foam roller with arms outstretched. When the actor shared the same spatial orientation as the participants, they tilted their upper body to the left when the actor was close to falling off the right side, and vice versa when the actor tilted too far left. These findings demonstrate that the intentions ascribed to actors can overrule the tendency to mimic perceived movements and induce compensatory movements.

In the context of planned coordination, the tendency to perform complementary movements may prevail over the tendency to mimic the actions of one's co-actor (van Schie, van Waterschoot, & Bekkering, 2008). Participants were asked to grasp an object in an imitative context or in a complementary action context. The object could be grasped either on top by making a precision grip or at the bottom by making a power grip. In the imitative context, participants imitated the grasp of a co-actor displayed on a computer screen, whereas in the complementary context, they acted as if they were taking over the object, performing a complementary grasp. On certain trials, a colour cue instructed participants to perform a particular grip, regardless of the interaction context. If the interaction context played no role, participants should always be faster at executing corresponding grips. However, the results showed that in the complementary action context, participants were faster at making a complementary grasping movement, whereas in the imitative context they were faster at

making an imitative grasping movement. This demonstrates that planning to perform a joint action involving complementary action can override the tendency to mimic the co-actor's movements and in fact, induces a tendency to perform the complementary movement.

### *Synergy of Planning and Action Simulation*

In the context of planned coordination, the matching between perceived and performed actions enables co-actors to apply predictive models in their motor system to accurately predict the upcoming actions of their co-actor, and to predict joint action outcomes. So far, only a few studies have directly addressed the role of action simulation in planned coordination.

Kourtis and colleagues studied action simulation processes in a triadic social interaction where two co-actors passed an object back and forth or lifted it alone, whereas the third actor always acted alone (Kourtis, Sebanz, & Knoblich, in press). A cue instructed the actors about which actions, if any, they should perform, and a second later they were prompted to act. The crucial comparison was between trials where participants did not have to act themselves, but expected that either their interaction partner would lift the object alone or that the 'loner' would lift the object alone. A neural marker of action simulation reflecting anticipatory motor activation was more pronounced when people anticipated the action of their interaction partner (Kilner, Vargas, Duval, Blakemore, & Sirigu, 2004) than when they anticipated the same action to be performed by the loner. Given that the actions of the partner and the loner were identical in all respects, this indicates that action simulation is constrained by the relation between actor and observer.

Planning to perform a joint action may also involve simulations of the co-actor's actions that lead to adjustments in individual action performance. Becchio and colleagues (2007) found that the movement kinematics of a reaching movement performed to grasp an

object differed depending on whether the actor reached for the object to place it on a hand-shaped pad or to place it on another person's palm at exactly the same location. The authors suggest that the smaller grip aperture and the lower speed at which the object was grasped in the joint action context reflect the need to handle the object in a way that makes it easy for the receiving person to grasp it. This may be taken as an indication that a simulation of the action to be performed by the partner guides individual action planning and control.

Action simulation likely plays a key role in joint actions that require close temporal coordination of different individual actions, such as playing a piano duet. Findings from studies of temporal coordination suggest two different ways in which action simulation may support planned coordination (Sebanz & Knoblich, 2009). On the one hand, actors may run multiple parallel action simulations to predict the timing of other co-actors' actions (Keller, Knoblich, & Repp, 2007). In support of this assumption, Keller and colleagues found that pianists playing one part of a duet together with a recording of the other part of the duet were better synchronized when playing together with a recording of their own earlier performance than when trying to synchronize with another pianist's performance. This may indicate that they used internal models in their motor system to predict the performance of both parts of the duet (their own and the one they synchronized with), which led to the best result when the actions to which they applied the models were their own earlier actions.

However, action simulation can also support temporal coordination if the target of the prediction is the timing of jointly produced events (Knoblich, & Jordan, 2003). Rather than generating separate predictions for their own and a co-actor's performance, agents might generate predictions regarding the temporal consequences of their combined efforts. Such predictions about joint action outcomes can only be made, however, after agents have had the opportunity to learn about regularities between their own actions, others' actions, and the resulting effects. This was demonstrated in a study where participants were instructed to keep

a circle on top of a target moving horizontally along the computer screen, using an “acceleration” and a “deceleration” key (Knoblich, & Jordan, 2003). Participants performed the task alone, controlling both keys, or in pairs, controlling one of the keys each. After considerable practice, joint task performance was as good as individual performance, but only when participants received auditory feedback about the timing of each other’s actions. This suggests that accurate predictions about the timing of joint action outcomes can be made if agents have had the opportunity to trace back the consequences of their combined actions to their individual contributions.

#### 4. Discussion

The evidence reviewed above shows that emergent coordination and planned coordination each support joint action. Emergent coordination can occur spontaneously between individuals who have no plan to perform actions together and relies on perception action couplings that make multiple individuals act in similar ways. In planned coordination agents plan their own actions in relation to joint action outcomes or in relation to others’ actions. Joint task representations and joint perceptions support these planning processes.

Most forms of joint action likely require both emergent and planned coordination because there are complementary limits on what each can achieve. On the one hand, planning alone does not make people act at the right time, fall into synchrony or predict others’ upcoming actions based on their own action repertoire. Although planning can prepare actors to perform their individual parts of a joint action, it does not guarantee successful implementation. Emergent coordination is likely the key to dealing with the real time aspects of joint action. On the other hand, emergent coordination alone is limited in that it does not allow people to distribute different parts of a task among themselves, nor to adjust their actions to others’ so as to flexibly achieve joint outcomes. These aspects of joint action

require planned coordination. The complementary limits of emergent and planned coordination suggest that it is the synergy of emergent and planned coordination that allows people to make music together, play team sports, or build a house.

This synergy is partly a matter of how planned coordination modulates mechanisms of emergent coordination: examples discussed above include greater entrainment in planned social interactions, the activation of action simulations for co-actors but not independent third-parties, and, under the heading of perception action matching, the possibility of performing actions which complement rather than match observed actions depending on either the nature of one's own task or one's representation of the observed agent's task. But the synergy also involves modulation of planned by emergent coordination, as where perception of joint affordances causes participants to switch from individual to joint action and where action simulation of a partner's next action affects one's own action planning.

One big challenge for future research on joint action is to specify in more detail how emergent coordination and planned coordination work together. How can joint task representations tap into mechanisms of entrainment, perception-action matching, and predictive action simulation? Which perceptions need to be shared so that mechanisms of planned and emergent coordination will act in combination? Does emergent coordination have a role in how joint action plans are set up and how roles are distributed between individual actors? What is the role of emergent coordination in generating joint perceptions?

A further challenge for joint action research is to discover interfaces that allow agents to integrate the more basic processes of emergent and planned coordination with the higher-level representations and processes postulated in theory of mind research such as common knowledge and mental state attribution. It is plausible that many cases of joint action, particularly those involving many distinct steps such as putting up a large tent on a wet and windy hill, depend on interlocking intentions and commitments in addition to emergent and



planned coordination. How do attributions of intention and knowledge in the pursuit of joint action goals interact with mechanisms of emergent and planned coordination? Some of the studies reviewed above indicate the possibility that what agents believe, the mood they are in, and their social relations to each other modulate the processes that are at the heart of performing joint actions. For instance, we saw that joint task representations can depend on beliefs about the status of a partner as an agent. To what extent can joint task representations also be modulated by explicit beliefs about the partner's task, or by beliefs about the partner's beliefs or intentions about one's own task?

We have also seen that both planned and emergent coordination may sometimes conflict with the avowed intentions of agents; certainly neither form of coordination appears to depend on agents making the attributions of mental states required for sharing intentions in any elaborate sense (e.g. Bratman, 1992). This raises the possibility that mental state attribution may sometimes be integrated only indirectly with emergent and planned coordination. To illustrate, recall that sometimes how close agents are to each other in space may affect their joint task representations. Consequently, mental state attribution might lead people to position themselves in ways that affect their joint task representations. Further questions concern whether and how emergent or planned coordination modulate attribution of mental states for joint action. Here the studies linking rapport with synchronised behaviour provide one possible model. Coordination cues may also allow agents to draw conclusions about the chances of successful joint action with another agent. Furthermore, agents may be sensitive to coordination cues that indicate whether their desires or beliefs are incompatible with their partner's.

Discovering interfaces between higher-level representations of minds and actions on the one hand and planned and emergent coordination on the other may provide psychologists studying human perception, action, and cognition with the opportunity to have a major impact

on the design of robots that are built to engage in action with humans (e.g., Braun, Ortega, & Wolpert, 2009; Breazeal, 2002; Wachsmuth & Knoblich, 2008). For instance, engineers designing these robots face the problem of effectively distributing the workspace between human and machine (Vesper, Soutschek, & Schuboe, 2009) and enabling haptic interactions such as joint object manipulation (Bosga & Meulenbroek, 2007; Reed et al., 2006), or jointly carrying objects while walking (Streuber, 2008).

Finally, psychological research on joint action may also lead to a fruitful exchange between experimental psychology and different disciplines in the humanities specialized in the use of discursive, observational, and phenomenological methods (DeJaegher, DiPaolo, & Gallagher, in press), especially musicology, anthropology, and philosophy. Joint actions are central in music history and music performance (Clayton, Sager, & Will, 2004; Keller, 2008) and play a key role in most worldly and religious rituals (Vogeley & Roepstorff, 2009). Thus joint action can serve as a platform for planned and emergent coordination across disciplines.

## 5. References

- Aglioti, S. M., Cesari, P., Romani, M., & Urgesi, C. (2008). Action anticipation and motor resonance in elite basketball players. *Nature Neuroscience*, *11*(9), 1109-1116.
- Atmaca, S., Sebanz, N., Prinz, W., & Knoblich, G. (2008). Action co-representation: The joint SNARC effect. *Social Neuroscience*, *3*, 410-420.
- Bach, P. & Tipper, S.P. (2007). Implicit action encoding influences personal-trait judgments. *Cognition*, *102*, 151-178.
- Baron-Cohen, S., Wheelwright, S., Hill, J., Rast, Y., & Plumb, I. (2001). The 'Reading the Mind in the eyes' test revised version: A study with normal adults, and adults with Asperger Syndrome or High-Functioning autism. *Journal of Child Psychology and Psychiatry*, *42*, 241-252.
- Bates, A. T., Patel, T. P., & Liddle, P. F. (2005). External behavior monitoring mirrors internal behavior monitoring: error-related negativity for observed errors. *Journal of Psychophysiology*, *19*(4), 281-288.
- Becchio, C., Sartori, L., Bulgheroni, M., & Castiello, U. (2008). Both your intention and mine are reflected in the kinematics of my reach to grasp movement. *Cognition*, *106*, 894-912.
- Bernieri, F. (1988). Coordinated movement and rapport in teacher-student interactions. *Journal of Nonverbal Behavior*, *24*, 120-138.
- Bertenthal, B. I., Longo, M. R., & Kosobud, A. (2006). Imitative response tendencies following observation of intransitive actions. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 210-225.
- Boeckler, A., Knoblich, G., & Sebanz, N. (submitted). Giving a helping hand: Effects of joint attention on mental rotation of body parts.

- Bosga, J., & Meulenbroek, R.G.J. (2007). Joint-action coordination of redundant force contributions in a virtual lifting task. *Motor Control*, 11, 235-258.
- Brass, M., Bekkering, H., & Prinz, W. (2001). Movement observation affects movement execution in a simple response task. *Acta Psychologica*, 106, 3-22.
- Brass, M. & Heyes, C. M. (2005) Imitation: Is cognitive neuroscience solving the correspondence problem? *Trends in Cognitive Sciences*, 9, 489-495.
- Bratman, M. (1992). Shared Cooperative Activity. *The Philosophical Review*, 101(2), 327-341.
- Bratman, M. (2009). Modest Sociality and the Distinctiveness of Intention. *Philosophical Studies*, 144(1), 149-165.
- Braun, D.A., Ortega, P.A., & Wolpert, D.M. (2009). Nash equilibria in multi-agent motor interactions. *PLoS Computational Biology*, 5(8), e1000468.
- Breazeal, C. (2002). *Designing sociable robots*. Cambridge, MA: MIT Press.
- Brennan, S. E., Chen, X., Dickinson, C., Neider, M., & Zelinsky, G. (2007). Coordinating cognition: The costs and benefits of shared gaze during collaborative search. *Cognition*, 106, 1465-1477.
- Brennan, S. E., & Hanna, J. E. (2009). Partner-specific adaptation in dialogue. *Topics in Cognitive Science*, 1, 274-291.
- Brownell, C. A., Ramani, G. B., & Zerwas, S. (2006). Becoming a social partner with peers: Cooperation and social understanding in one- and two-year-olds.
- Call, J. (2009). Contrasting the social cognition of human and nonhuman apes: The shared intentionality hypothesis. *Topics in Cognitive Science*, 1(2), 368-379.
- Calvo-Merino, B., Glaser, D., Grèzes, J., Passingham, R., & Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral*

*Cortex*, 15, 1243-1249.

- Carpenter, M. (2009). Just how joint is joint action in infancy? *Topics in Cognitive Science*, 1(2), 380–392.
- Castiello, U., Lusher, D., Mari, M., Edwards, M., & Humphreys, G. W. (2002). Observing a human or a robotic hand grasping an object: differential motor priming effects. In *Common Mechanisms in Perception and Action. Series: Attention and Performance XIX* (pp. 315-333). Oxford: Oxford University Press.
- Chartrand, T. L., & Bargh, J. A. (1999). The chameleon effect: The perception-behavior link and social interaction. *Journal of Personality & Social Psychology*, 76(6), 893–910.
- Clark, A. (2007). *Being there: Putting Brain, Body, and World together again*. Cambridge, MA: MIT Press.
- Clark, H. H. (1996). *Using language*. Cambridge, UK: Cambridge University Press.
- Clark, H. H. (2005). Coordinating With Each Other in a Material World. *Discourse Studies*, 7, 507-525.
- Clayton, M., Sager, R., & Will, U. (2004). In time with the music: The concept of entrainment and its significance for ethnomusicology. *ESEM CounterPoint*, 11, 96-99.
- Condon, W. (1976). An analysis of behavioral organization. *Sign Language Studies*, 13, 285-318.
- Condon, W. S., & Ogston, M. B. (1966). Sound film analysis of normal and pathological behavior patterns. *The Journal of Nervous and Mental Disease*, 143(4), 338-347.
- Cross, E. S., Hamilton, A. F., & Grafton, S. T. (2006). Building a motor simulation de novo: Observation of dance by dancers. *Neuroimage*, 31, 1257–1267.
- De Bruijn, E. R. A., Miedl, S. F., & Bekkering H. (2008). Fast responders have blinders on: ERP correlates of response inhibition in competition. *Cortex*, 44(5), 580-586.

- Dehaene, S. (1997). *The number sense*. New York: Oxford University Press.
- DeJaegher, H., DiPaolo, E., & Gallagher, S. (in press). Can social interaction constitute social cognition? *Trends in Cognitive Sciences*.
- De Maeght, S., & Prinz, W. (2004) Action induction through action observation. *Psychological Research*, 68(2–3), 97–114.
- Edwards, M. G., Humphreys, G. W., & Castiello, U. (2003). Motor facilitation following action observation: A behavioural study in prehensile action. *Brain and Cognition*, 53, 495-502.
- Flanagan, J. R., & Johansson, R. S. (2003). Action plans used in action observation. *Nature*, 424, 769-771.
- Fowler, C. A. Richardson, M. J., Marsh, K. L., & Shockley, K. D. (2008). Language use, coordination, and the emergence of cooperative action. In A. Fuchs & V. Jirsa (Eds.) *Coordination: Neural, Behavioral and Social Dynamics*. Springer.
- Frischen, A., Loach, D., & Tipper, S. P. (2009). Seeing the world through another person's eyes: Simulating selective attention via action observation. *Cognition*, 111(2), 212-218.
- Galantucci, B. (2009). Experimental semiotics: A new approach for studying communication as a form of joint action. *Topics in Cognitive Science*, 1(2), 393-410.
- Georgiou, I., Becchio, C., Glover, S., & Castiello U. (2006). Different action patterns for cooperative and competitive behaviour. *Cognition*, 102, 415-433.
- Gibson, J. J. (1977). The theory of affordances. In R. Shaw & J. Bransford (Eds.), *Perceiving, acting, and knowing: Toward an ecological psychology* (pp. 67-82). Hillsdale, NJ: Erlbaum.
- Gilbert, M. (1992). *On Social Facts*. Princeton, NJ: Princeton University Press.

- Gilbert, M. (2006). Rationality in collective action. *Philosophy of the Social Sciences*, 36(1) 3–17.
- Goebel, W., & Palmer, C. (2009). Synchronization of timing and motion among performing musicians. *Music Perception*, 26, 427–438.
- Gold, N., & Sugden, R. (2007). Collective Intentions and Team Agency. *Journal of Philosophy*, 104(3), 109–137.
- Gräfenhain, M., Behne, T., Carpenter, M., & Tomasello, M. (2009). Young children's understanding of joint commitments. *Developmental Psychology*, 45, 1430–1443.
- Griffiths, D., & Tipper, S. P. (2009). Priming of reach trajectory when observing actions: hand-centred effects. *Quarterly Journal of Experimental Psychology*, 62(12), 2450–2470.
- Guagnano, D., Rusconi, E., & Umiltà, C. (in press). Sharing a task or sharing space? On the effect of a confederate in action coding. *Cognition*.
- Haeberle, A., Schuetz-Bosbach, S., Laboissiere, R., & Prinz, W. (2008). Ideomotor action in cooperative and competitive settings. *Social Neuroscience*, 3(1), 26–36.
- Haken, H., Kelso, J. A. S., & Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biological Cybernetics*, 51(5), 347–356.
- Hamilton, A., Wolpert, D., & Frith, U. (2004). Your own action influences how you perceive another person. *Current Biology*, 14, 493–498.
- Harrison, S. J., & Richardson, M. J. (2009). Horsing around: Spontaneous four-legged coordination. *Journal of Motor Behaviour*, 41, 519–524.
- Heed, T., Habets, B., Sebanz, N., & Knoblich, G. (in press). Others' actions reduce crossmodal integration in peripersonal space. *Current Biology*.
- Hommel, B., Colzato, L. S., & van den Wildenberg, W. P. M. (2009). How social are task representations? *Psychological Science*, 20, 794–798.

- Hommel, B., Muesseler, J., Aschersleben, G., & Prinz, W. (2001). The theory of event coding (TEC). *Behavioral and Brain Sciences*, 24, 849-937.
- Hove, M. J., & Risen, J. L. (2009). It's all in the timing: Interpersonal synchrony increases affiliation. *Social Cognition*, 27(6), 949-961.
- Hutchins, E. (1995). How a cockpit remembers its speeds. *Cognitive Science*, 19, 265–288.
- Huygens, C. (1673/1986). *The pendulum clock or geometrical demonstrations concerning the motion of pendula as applied to clocks*, trans. R. J. Blackwell, Ames: Iowa State University Press.
- Issartel, J., Marin, L., Cadopi, M. (2007). Unintended interpersonal co-ordination: Can we march to the beat of our own drum? *Neuroscience Letters*, 441(3), 174-179.
- Jax, S. A. & Rosenbaum, D. A. (2007). Hand path priming in manual obstacle avoidance: Evidence that the dorsal stream does not only control visually guided actions in real time. *Journal of Experimental Psychology: Human Perception and Performance*, 33, 425-441.
- Jeannerod, M. (1999). The 25th Bartlett Lecture. To act or not to act: Perspectives on the representation of actions. *Quarterly Journal of Experimental Psychology*, 52A, 1-29.
- Jeka, J. J., Kelso, J. A. S., & Kiemel, T. (1993). Spontaneous transitions and symmetry: Pattern dynamics in human four-limb coordination. *Human Movement Science*, 12, 627-651.
- Jones, K. S. (2003). What is an affordance? *Ecological Psychology*, 15, 107–114.
- Keller, P. E., Knoblich, G., & Repp, B. H. (2007). Pianists duet better when they play with themselves: On the possible role of action simulation in synchronization. *Consciousness and Cognition*, 16(1), 102-111.



- Keller, P. E., & Repp, B. H. (2004). When two limbs are weaker than one: Sensorimotor syncopation with alternating hands. *Quarterly Journal of Experimental Psychology*, 57A(6), 1085-1101.
- Kendon, A. (1970). Movement coordination in social interaction. *Acta Psychologica*, 32, 1-25.
- Kilner, J. M., Paulignan, Y., & Blakemore, S. J. (2003). An interference effect of observed biological movement on action. *Current Biology*, 13, 522-525.
- Kirschner, S. & Tomasello, M. (2009). Joint Drumming: Social Context Facilitates Synchronization in Preschool Children. *Journal of Experimental Child Psychology*, 102(3), 299-314.
- Knoblich, G., & Flach, R. (2001). Predicting the effects of actions: Interactions of perception and action. *Psychological Science*, 12, 467-472.
- Knoblich, G., & Jordan, S. (2002). The mirror system and joint action. In M. I. Stamenov & V. Gallese (Eds.): *Mirror Neurons and the Evolution of Brain and Language* (pp. 115-124). Amsterdam: John Benjamins.
- Knoblich, G. & Jordan, S. (2003). Action coordination in groups and individuals: Learning anticipatory control. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 29, 1006-1016.
- Knoblich, G., & Sebanz, N. (2006). The social nature of perception and action. *Current Directions in Psychological Science*, 15, 99-104.
- Knoblich, G., & Sebanz, N. (2008). Evolving intentions for social interaction: From entrainment to joint action. *Philosophical Transactions of the Royal Society B*, 363, 2021-2031.

- Knoblich, G., Seigerschmidt, E., Flach, R., & Prinz, W. (2002). Authorship effects in the prediction of handwriting strokes. *Quarterly Journal of Experimental Psychology*, 55A, 1027-1046.
- Knuf, L., Aschersleben, G., & Prinz, W. (2001). An analysis of ideomotor action. *Journal of Experimental Psychology: General*, 130, 779-798.
- Konvalinka, I., Vuust, P., Roepstorff, A., & Frith, C. D. (in press). Follow you, follow me: Continuous mutual prediction and adaptation in joint tapping. *Quarterly Journal of Experimental Psychology*.
- Kourtis, D., Sebanz, N., & Knoblich, G. (in press). Favouritism in the motor system: social interaction modulates action simulation. *Biology Letters*.
- Kuhbandner, C., Pekrun, R., & Maier, M. A. (in press). The role of positive and negative affect in the 'mirroring' of other persons' actions. *Cognition & Emotion*.
- Kutz, C. (2000). Acting Together. *Philosophy and Phenomenological Research*, 61(1), 1-31.
- Lakin, J. L., Jefferis, V. E., Cheng, C. M., & Chartrand, T. L. (2003). The Chameleon Effect as social glue: Evidence for the evolutionary significance of nonconscious mimicry. *Journal of Nonverbal Behavior*, 27, 145-162.
- Liepelt, R., von Cramon, D. Y., & Brass, M. (2008). What is matched in direct matching? Intention attribution modulates motor priming. *Journal of Experimental Psychology: Human Perception and Performance*, 34(3), 578-591.
- Liszkowski, U., Carpenter, M., & Tomasello, M. (2008). Twelve-month-olds communicate helpfully and appropriately for knowledgeable and ignorant partners. *Cognition*, 108(3), 732-739.
- Marsh, K. L., Richardson, M. J., & Schmidt, R. C. (2009). Social connection through joint action and interpersonal coordination. *Topics in Cognitive Science*, 1(2), 320-339.

- Mechner, F., & Knoblich, G. (2004). Do muscles matter in bimanual coordination? *Journal of Experimental Psychology: Human Perception and Performance*, 30, 490-503.
- Melis, A. P., Hare, B., & Tomasello (2006). Chimpanzees recruit the best collaborators. *Science*, 311(5765), 1297-1300.
- Milanese, N., Iani, C., & Rubichi, S. (2010). Shared learning shapes human performance: Transfer effects in task sharing. *Cognition*, 116(1), 15-22.
- Miles, L. K., Nind, L. K., & Macrae, C. N. (2009). The rhythm of rapport: Interpersonal synchrony and social perception. *Journal of Experimental Social Psychology*, 45(3), 585-589.
- Mottet, D., Guiard, Y., Ferrand, T., & Bootsma, R. J. (2001). Two-handed performance of a rhythmical Fitts task by individuals and dyads. *Journal of Experimental Psychology-Human Perception and Performance*, 27(6), 1275-1286.
- Neda, Z., Ravasz, E., Brechte, Y., Vicsek, T., & Barabasi, A.-L. (2000). The sound of many hands clapping. *Nature*, 403, 849-850.
- Oullier, O., de Guzman, G.C., Jantzen, K.J., Lagarde, J., & Kelso, J.A.S. (2008). Social coordination dynamics: Measuring human bonding. *Social Neuroscience*, 3(2), 178-192.
- Pacherie, E., & Dokic, J. (2006). From mirror neurons to joint actions. *Cognitive Systems Research*, 7, 101-112.
- Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology*, 9, 129-154.
- Ramnani, N., & Miall, R. C. (2004). A system in the human brain for predicting the actions of others. *Nature Neuroscience*, 7(1), 85 - 90.

- Reed, K., Peshkin, M., Hartmann, M.J., Grabowecky, M., Patton, J., & Vishton, P.M. (2006).  
Haptically linked dyads: Are two motor-control systems better than one?  
*Psychological Science*, 17(5), 365-366.
- Richardson, D. C., & Dale, R. (2005). Looking to understand: The coupling between speakers' and listeners' eye movements and its relationship to discourse comprehension.  
*Cognitive Science*, 29, 1046-1060.
- Richardson, D. C., Dale, R., & Kirkham, N. Z. (2007). The art of conversation is coordination: Common ground and the coupling of eye movements during dialogue.  
*Psychological Science*, 18(5), 407-413.
- Richardson, D. C., Dale, R., & Shockley, K. (2008). Synchrony and swing in conversation: coordination, temporal dynamics and communication. In I. Wachsmuth, M. Lenzen, & G. Knoblich (Eds.), *Embodied Communication*, Oxford, UK: Oxford University Press.
- Richardson, D. C., Dale, R. & Tomlinson Jr, J. M. (2009) Conversation, gaze coordination and beliefs about visual context. *Cognitive Science*, 33, 1468-1482.
- Richardson, M. J., Campbell, W. L., & Schmidt, R. C. (2009). Movement interference during action observation as emergent coordination. *Neuroscience Letters*, 449(2), 117-122.
- Richardson, M. J., Marsh, K. L., & Baron, R. M. (2007). Judging and Actualizing Intrapersonal and Interpersonal Affordances. *Journal of Experimental Psychology: Human Perception and Performance*, 33, 845-859.
- Richardson, M. J., Marsh, K. L., Isenhower, R., Goodman, J., & Schmidt, R. C. (2007). Rocking together: Dynamics of intentional and unintentional interpersonal coordination. *Human Movement Science*, 26, 867-891.
- Rizzolatti, G., & Sinigaglia, C. (2010). The functional role of the parieto-frontal mirror circuit: interpretations and misinterpretations. *Nature Reviews Neuroscience* 11, 264-274.

- Roth, A. S. (2004). Shared Agency and Contralateral Commitments. *The Philosophical Review*, 113(3), 359-410.
- Ruys, K. I., & Aarts, H. (in press). When competition merges people's behavior. When competition merges people's behavior: Interdependency activates shared action representations, *Journal of Experimental Social Psychology*.
- Samson, D., Apperly, I. A., Braithwaite, J. J., Andrews, B. J. & Bodely Scott, S. E. (in press). Seeing it their way: Evidence for rapid an involuntary computation of what other people see. *Journal of Experimental Psychology: Human Perception and Performance*.
- Schmidt, R. C., Bienvenu, M., Fitzpatrick, P. A., & Amazeen, P. G. (1998). A comparison of within- and between-person coordination: Coordination breakdowns and coupling strength. *Journal of Experimental Psychology: Human Perception and Performance*, 24, 884-900.
- Schmidt, R. C., Carello, C., & Turvey, M. T. (1990). Phase transitions and critical fluctuations in the visual coordination of rhythmic movements between people. *Journal of Experimental Psychology: Human Perception and Performance*, 16, 227-247.
- Schmidt, R.C., Fitzpatrick, P., Caron, R., & Mergeche, J. (in press). Understanding social motor coordination. *Human Movement Science*.
- Schmidt, R. C., & O'Brien, B. (1997). Evaluating the dynamics of unintended interpersonal coordination. *Ecological Psychology*, 9, 189-206.
- Schmidt, R. C., & Richardson, M. J. (2008). Dynamics of Interpersonal Coordination. In A. Fuchs & V. Jirsa (Eds.) *Coordination: Neural, Behavioral and Social Dynamics*. Springer.

- Schmidt, R. C., & Turvey, M. T. (1994). Phase-entrainment dynamics of visually coupled rhythmic movements. *Biological Cybernetics*, 70, 369-376.
- Schuch, S. & Tipper, S. P. (2007). On observing another person's actions: Influences of observed inhibition and errors. *Perception & Psychophysics*, 69, 828-837.
- Searle, J. R. (1990 [2002]). Collective Intentions and Actions. In *Consciousness and Language* (pp. 90-105). Cambridge: Cambridge University Press.
- Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: bodies and minds moving together. *Trends in Cognitive Science*, 10(2), 70-76.
- Sebanz, N., & Knoblich, G. (2009). Prediction in Joint Action: What, when, and where. *Topics in Cognitive Science*, 1, 353-367.
- Sebanz, N., Knoblich, G., & Prinz, W. (2005). How two share a task: Corepresenting Stimulus-Response mappings. *Journal of Experimental Psychology: Human Perception and Performance*, 31, 1234-1246.
- Sebanz, N., Knoblich, G., & Prinz, W. (2003). Representing others' actions: Just like one's own? *Cognition*, 88, B11-B21.
- Sebanz, N., Knoblich, G., Prinz, W., & Wascher, E. (2006). Twin Peaks: An ERP study of action planning and control in co-acting individuals. *Journal of Cognitive Neuroscience*, 18, 859-870.
- Sebanz, N., Knoblich, G., Stumpf, L., & Prinz, W. (2005). Far from action blind: Representation of others' actions in individuals with autism. *Cognitive Neuropsychology*, 22, 433-454.
- Sebanz, N., & Shiffrar, M. (2007). Bodily bonds: Effects of Social Context on Ideomotor Movements. In Y. Rossetti, M. Kawato, & Patrick Haggard (Eds.), *Sensorimotor foundations of higher cognition (Attention and Performance, XXII)*. Oxford, UK: Oxford University Press.

- Semin, G. R. & Cacioppo, J. T. (2008). Grounding Social Cognition: Synchronization, Entrainment, and Coordination. In G.R. Semin & E.R. Smith (Eds.), *Embodied grounding: Social, cognitive, affective, and neuroscientific approaches* (pp.119-147). New York: Cambridge University Press.
- Semin, G. R., & Smith, E. R. (Eds.) (2008). *Embodied grounding: Social, cognitive, affective, and neuroscientific approaches*. New York: Cambridge University Press.
- Shintel, H & Keysar, B. (2009). Less is more: A minimalist account of joint action in communication. *Topics in Cognitive Science, 1*, 260-273.
- Shockley, K. D., Baker, A. A., Richardson, M. J., & Fowler, C. A. (2007). Articulatory constraints on interpersonal postural coordination. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 201-208.
- Shockley, K., Butwill, M., Zbilut, J., & Webber, C. (2002). Cross recurrence quantification of coupled oscillators. *Physics Letters A, 305*, 59–69.
- Shockley, K., Santana, M. V., & Fowler, C. A. (2003). Mutual interpersonal postural constraints are involved in cooperative conversation. *Journal of Experimental Psychology: Human Perception and Performance, 29(2)*, 326-332.
- Spence, C., Pavani, F., Maravita, A., & Holmes, N. (2004). Multisensory contributions to the 3-D representation of visuotactile peripersonal space in humans: Evidence from the crossmodal congruency task. *Journal of Physiology, 98*, 171-189.
- Spivey, J. M. (2007). *The continuity of mind*. New York, NY: Oxford University Press.
- Stanley J., Gowen, E., & Miall, R. C. (2007) Interference in performed movement during observation of a moving dot stimulus. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 915-926.

- Stoffregen, T. A., Givens, M. R., Villard, S., Yank, J. R., & Shockley, K. (2009). Interpersonal postural coordination on rigid and non-rigid surfaces. *Motor Control*, 13, 471-483.
- Streuber, S. (2008). *Embodied in cyberspace: Coordination processes in a joint action transportation task*. Unpublished thesis.
- Stürmer, B., Aschersleben, G., & Prinz, W. (2000). Correspondence effects with manual gestures and postures: a study of imitation. *Journal of Experimental Psychology: Human Perception and Performance*, 26(6), 1746-1759.
- Tognoli, E., Lagarde, J., De Guzman, G. C. & Kelso, J. A. S. (2007). From the cover: The phi-complex as a neuromarker of human social coordination. *Proceedings of the National Academy of Sciences*, 104, 8190-8195.
- Tollefsen, D. (2005). Let's pretend! Children and joint action. *Philosophy of the Social Sciences*, 35, 75–97.
- Tomasello, M. (2009). *Why We Cooperate*. Cambridge, MA: MIT Press.
- Tomasello, M., Carpenter, M., Call, J., Behne, T., & Moll, H. (2005). Understanding and sharing intentions: The origins of cultural cognition. *Behavioral and Brain Sciences*, 28, 675 - 691.
- Trevarthen, C. (1979). Communication and cooperation in early infancy: A description of primary intersubjectivity. In M. Bullowa (Ed.), *Before speech* (pp. 321-343), Cambridge, UK: Cambridge University Press.
- Tsai, C.-C., Kuo, W.-J., Hung, D. L., & Tzeng, O. J.-L. (2008). Action co-representation is tuned to other humans. *Journal of Cognitive Neuroscience*, 20, 2015-2024.
- Tsai, C.-C., Kuo, W.-J., Jing, J.-T., Hung, D. L., & Tzeng, O. J.-L. (2006). A common coding framework in self-other interaction: Evidence from joint action task. *Experimental Brain Research*, 175, 353-362.



- Tsai, C.-C., & Brass, M. (2007). Does the human motor system simulate Pinocchio's actions? *Psychological Science, 18*, 1058-1062.
- Tucker, M. & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance, 24*, 3, 830-846.
- Valdesolo, P., Ouyang, J., & DeSteno, D. A. (2010). The Rhythm of Joint Action: Synchrony promotes cooperative ability. *Journal of Experimental Social Psychology, 46*, 693–695.
- Van Baaren, R. B., Holland, R. W., Kawakami, K., & van Knippenberg, A. (2004). Mimicry and pro-social behavior. *Psychological Science, 15*, 71-74.
- Van Baaren, R. B., Holland, R. W., Steenaert, B., & van Knippenberg, A. (2003). Mimicry for money: Behavioral consequences of imitation. *Journal of Experimental Social Psychology, 39*, 393-398.
- Van Baaren, R., Janssen, L., Chartrand, T., & Dijksterhuis, A. (2009). Where is the love? The social consequences and moderators of mimicry in humans. *Philosophical Transactions of the Royal Society B, 2381*-2389.
- Van Schie, H. T., Mars, R. B., Coles, M. G. H., & Bekkering, H. (2004). Modulation of activity in medial frontal and motor cortices during error observation. *Nature Neuroscience, 7* (5), 549-554.
- Van Schie, H. T., Waterschoot, B. M., & Bekkering, H. (2008). Understanding action beyond imitation: Reversed compatibility effects of action observation in imitation and joint action. *Journal of Experimental Psychology: Human Perception and Performance, 34*(6), 1493-1500.

- Van Ulzen, N. R., Lamoth, C. J., Daffertshofer, A., Semin, G. R. & Beek, P. J. (2008). Characteristics of instructed and uninstructed interpersonal coordination while walking in pairs. *Neuroscience Letters*, 432(2), 88-93.
- Van Der Wel, R. P., Fleckenstein, R., Jax, S., & Rosenbaum, D. A. (2007). Hand path priming in manual obstacle avoidance: Evidence for abstract spatio-temporal forms in human motor control. *Journal of Experimental Psychology: Human Perception and Performance*, 33, 1117-1126.
- Vesper, C., Butterfill, S., Knoblich, G., & Sebanz, N. (2010). A minimal architecture for joint action. *Neural Networks*, in press.
- Vesper, C., Soutschek, A., & Schuboe, A. (2009). Motion coordination affects movement parameters in a joint pick-and-place task. *Quarterly Journal of Experimental Psychology*, 62(12), 2418-2432.
- Vogeley, K., & Roepstorff, A. (2009). Contextualizing culture and social cognition. *Trends in Cognitive Sciences*, 13, 511-516,
- Von Uexkuell, J. (1920). *Theoretische Biologie* [Theoretical biology]. Berlin, Germany: Springer.
- Wachsmuth, I., & Knoblich, G. (Eds.) (2008). *Modelling communication with robots and virtual humans*. Berlin: Springer.
- Wachsmuth, I., Lenzen, M., & Knoblich, G. (Eds.) (2008). *Embodied Communication*. Oxford: Oxford University Press.
- Warneken, F., & Tomasello, M. (2007). Helping and cooperation at 14 months of age. *Infancy*, 11(3), 271-294.
- Welsh, T. N. (2009). When  $1 + 1 = 1$ : The unification of independent actors revealed through joint Simon effects in crossed and uncrossed effector conditions. *Human Movement Science*, 28(6), 726-737.

- Welsh, T. N., Elliott, D., Anson, G. G., Dhilion, V., Weeks, D. J., Lyons, J. L., & Chua, Romeo (2005). Does Joe influence Fred's action? Inhibition of return across different nervous systems. *Neuroscience Letters*, 385(2), 99-104.
- Welsh, T. N., Higgins, L., Ray, M., & Weeks, D. J. (2007). Seeing vs. believing: Is believing sufficient to activate the processes of response co-representation? *Human Movement Science*, 26, 853-866.
- Welsh, T. N., Lyons, J., Weeks, D. J., Anson, J. G., Chua, R., Mendoza, J. E., & Elliott, D. (2007). Within- and between-nervous system inhibition of return: Observation is as good as performance. *Psychonomic Bulletin & Review*, 14, 950-956.
- Wilson, M., & Knoblich, G. (2005). The case for motor involvement in perceiving conspecifics. *Psychological Bulletin*, 131, 460-473.
- Wiltermuth, S. S. & Heath, C. (2009). Synchrony and cooperation. *Psychological Science*, 20, 1-5.
- Wolpert, D. M., Doya, K., & Kawato, M. (2003). A unifying computational framework for motor control and interaction. *Philosophical Transactions of the Royal Society of London B*, 358, 593-602.
- Woodworth, R. S. (1939). Individual and group behaviour. *The American Journal of Sociology*, 44(6), 823-828.
- Yoon, Humphreys, & Riddoch (in press). The paired-object affordance effect. *Journal of Experimental Psychology: Human Perception and Performance*.



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