Using Violations of Fitts' Law to Communicate during Joint Action

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Abstract

When people perform joint actions together, task knowledge is sometimes distributed asymmetrically such that one person has information that another person lacks. In such situations, interpersonal action coordination can be achieved if the knowledgeable person modulates basic parameters of her goal-directed actions in a way that provides relevant information to the less knowledgeable partner. We investigated whether systematic violations of predicted movement duration provide a sufficient basis for such communication. Results of a joint movement task show that knowledgeable partners spontaneously and systematically violated the predictions of Fitts' law in order to communicate if their partners could not see their movements. Unknowing partners had a benefit from these violations and more so if the violations provided a good signal-to-noise ratio. Together, our findings suggest that generating and perceiving systematic deviations from the predicted duration of a goal-directed action can enable non-conventionalized forms of communication during joint action.

Keywords: Joint action; signaling; coordination strategy; cooperation; communication; social cognition.

Introduction

When two or more people perform joint actions together, communication is often key to successful coordination. An obvious case is having a conversation (Clark, 1996), for instance, discussing the steps necessary to prepare dinner. But communication can also occur non-verbally, such as when someone waves to inform another of her presence or when nodding to indicate approval. These gestures are, like spoken language, purely communicative because they do not serve to achieve a specific action outcome – their exclusive purpose is to inform another person. However, there are many cases where the same action serves an instrumental purpose and informs another person at the same time: If a passenger occupying the window seat on a train starts stands up in a demonstrative way, then the instrumental purpose of her action is to leave her seat. At the same time she informs the person occupying the aisle about her intention to leave. Thus, there is a class of actions that concurrently serve instrumental as well as communicative goals (Pezzulo, Donnarumma, & Dindo, 2013).

What are the specific circumstances that trigger this class of actions? Previous studies have focused on joint actions where communication is needed because one person lacks information required to achieve a joint goal and therefore requires a knowledgeable partner to provide this information. It has been shown that knowledgeable partners exaggerate grip aperture (Sacheli, Tidoni, Pavone, Aglioti, & Candidi, 2013) or modulate kinematic properties such as movement amplitude or direction (Pezzulo et al., 2013; Vesper & Richardson, 2014) to convey knowledge their partners lack, even in interaction with young infants ('motionese'; Brand, Baldwin, & Ashburn, 2002).

There is also evidence that unknowledgeable partners perceive such modulations. For instance, it has been demonstrated that observers are sensitive to subtle kinematic differences in performance (Becchio, Sartori, Bulgheroni, & Castiello, 2008; Sartori, Becchio, & Castiello, 2011). However, in order to understand that a movement modulation is communicative, an observer will also need to understand the intended meaning of the modulation. Whereas verbal language and most gestures are conventional and thus based on associations between an arbitrary (linguistic) code and its meaning (Scott-Phillips, 2015), this may not be required to understand communicative modulations of instrumental actions. Instead, observers may understand kinematic signals by making use of their own motor system to predict the unfolding action of a communicator (Pezzulo et al., 2013; Wilson & Knoblich, 2005; Wolpert, Doya, & Kawato, 2003). Systematic deviations from these predictions may be taken as conveying particular meaning.

The aim of the present study was to ask whether movement duration provides a basis for establishing communication between a Leader and a Follower in this way. We hypothesized that Leaders should modulate movement speed to indicate target locations unknown to a Follower and that Followers should be able to use this information to choose where to move. Such communication should not depend on the Follower having visual access to the Leader's actions if the task context is shared. The reason is that motor simulation can be used to predict movement duration even in the absence of visual input (Umiltà et al., 2001; Vesper, van der Wel, Sebanz, & Knoblich, 2013).

Present study

We investigated whether and how people would communicatively modulate movement duration in a joint setting. Previous research demonstrated that observers can estimate with some precision the duration of (partially) hidden actions. For instance, observers can accurately predict when someone will re-appear behind an occluding object (Graf, Reitzner, Corves, Casile, Giese, & Prinz, 2007; Sparenberg, Topolinski, Springer, & Prinz, 2011). Here, we tested the hypothesis that joint action partners would use this temporal prediction ability in the service of communication. Specifically, we hypothesized that actors would convey distance information by systematically modulating movement duration.

To this end, we instructed pairs of participants to perform goal-directed hand movements from a starting location to one of three target locations (Figure 1), where matching targets was the goal of the joint action. One member of the dyad was the 'Leader' and knew the target location; the other member was the 'Follower' and did not know the target location. The task was sequential. First the Leader moved to the target, then the Follower attempted to move to the same target. Importantly, an externally triggered tone marked the start of a new trial and a second tone was triggered when Leaders arrived at the target location. There were three different joint conditions (Table 1): In 'Vision', Leaders and Followers could see each other. In 'Pitch', co-actors could not see each other but a tone of different pitch for each of the three locations sounded when the Leader arrived at a particular target location. In 'None', no such immediate source of information was available as Followers could not see the Leaders and Leaders' target hits always produced tones with the same pitch.

For the None condition, we predicted that Leaders would communicatively use the interval between start and arrival tone to create a source of information that would help Followers perform their task. For the two baseline conditions Vision and Pitch, we did not expect any communicative modulation of movement speed from Leaders since both conditions contained explicit target information (either in visual or auditory form) to be picked up by Followers, making additional communication irrelevant (Wilson & Sperber, 2004). Thus, we expected Followers to make use of the respective source of information by simply observing Leaders' movements or by discriminating the different target pitches.

The distance of target locations from the starting point and the target size was chosen so that the duration of Leaders' movements was expected to be equal to all three target locations according to Fitts' law (Fitts, 1954). Building on this law, that defines a tradeoff between distance and target size, the targets were proportionally larger for longer distances between start and target location. Previous research has shown that Fitts' law holds in performance and motor imagery (Decety & Jeannerod, 1995) and also in action observation (Grosjean, Shiffrar, & Knoblich, 2007).

We expected Leaders to strategically modulate their movements to create distinguishable time intervals for the three different target distances in order to provide target information to Followers. Leaders' communication could be quantified as systematic violations of Fitts' law. We expected that such violations would occur in the None condition but not in the other two conditions. An alternative possibility for communication in the None condition is that Leaders delay initiation of their movement and keep movement duration unchanged. To tease apart these two possibilities, we analyzed the movement onset (interval between the external tone and the start of the movement) separately from the movement time (interval between the initiation of the movement and arriving at the target). If participants modulated movement time rather than movement onset this would imply that they chose to convey communicative information via the same channel used for the instrumental action, although other options are available that clearly separate communicative and instrumental information.

Table 1: Design and main hypotheses.

	Vision	Pitch	None
Visual information available?	**Yes**	No	No
Pitch information available?	No	**Yes**	No
Modulation of Leader's action duration expected?	*No*	*No*	***Yes***

Method

Participants

Eleven women and thirteen men participated in randomly-matched pairs (three women only pairs, four men only pairs). Participants were between 21 and 33 years old (M = 26.4 years, SD = 3.0 years), right-handed and had normal or corrected-to-normal vision. The members of three pairs knew each other before the experiment. They gave prior written informed consent, received monetary compensation and were debriefed about the study purpose at the end of the experiment. The experiment was performed in accordance with the Declaration of Helsinki. In each pair, one participant was randomly assigned to the experimental role of 'Leader' and the other to the role of 'Follower'.

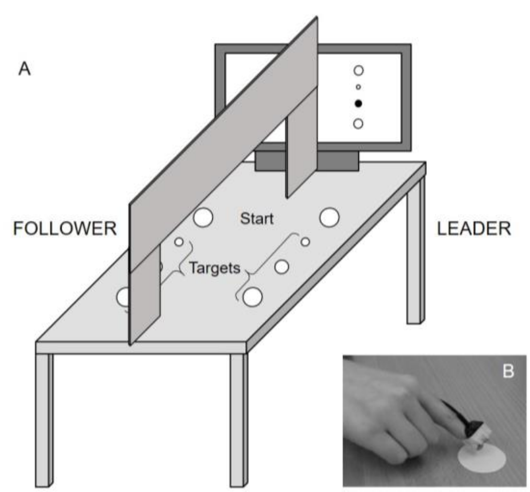

Figure 1: A: Schematic drawing of the experimental setup. Only Leaders received target information on the computer screen. B: Placement of the motion capture sensor.

Apparatus

An interactive real-time motion-capture setup was created for the purpose of the present experiment (Figure 1A). It consisted of a table with a row of four circles on each long side. The circle diameters were 4.8 cm for the start locations and 1.6 cm, 3.2 cm and 4.8 cm for the three targets. All circles were centrally aligned with a center-to-center distance of 20 cm. The index of difficulty (ID) according to Fitts' law (Fitts, 1954; ID = $\log_2(2A/W)$ with A: movement amplitude, W: target width) was 4.64 for all three targets.

The two participants were seated comfortably at the table. A cardboard partition in the middle of the table had an opening in the middle (85 cm long, 35 cm high) that could be covered with a black opaque cloth to prevent visual contact between participants. The partition also separated the stimulus display on a 24" Asus computer screen (resolution 1920 x 1080 pixels, refresh rate 60 Hz) such that Leaders and Followers could be presented with different information. The interactive setup was controlled online with a Polhemus G4 electro-magnetic motion capture system (www.polhemus.com) that recorded participants' movement data with a constant sampling rate of 120 Hz. Movement sensors were taped centrally onto the nail of each participant's right index finger (Figure 1B). The experimental procedure and data recording was controlled by Matlab 2014a.

Procedure

Participants received written instructions, which were verbally repeated before each block of the experiment. Leaders were explicitly made aware that they would need to help their partner: "Your partner will not know which target position is the correct one. For your partner, the only information about the target can come from your action. Your goal is to help your partner such that she/he will be able to reach the correct target position as fast as possible." Correspondingly, the Followers' instructions emphasized that their partner would have relevant task information: "Your partner will know which target position is the correct one, but you will not know this in advance – for you, the only information about the target can come from your partner's action. Your partner's goal is to help you such that you will be able to reach the correct target position as fast as possible." Participants were also informed that they were not allowed to speak to each other.

The first block, an individual training ('Individual'), was completed only by the participant with the Leader role, while the Follower waited in a separated part of the room. Afterwards, both participants performed three blocks of trials together with short breaks in between (Table 1). In the 'Vision' block, co-actors could see each other's hand movements. In the 'Pitch' block, visual access was prevented but Leaders' target arrival triggered differently pitched tones. In the 'None' block, neither visual access nor pitch information was available. The order of the three joint blocks was counterbalanced across participant pairs.

Each block began with a short calibration procedure to acquire the spatial coordinates of participants' finger positions at start and targets to guide the online control of the experiment by the motion capture system. Then, after three training trials to allow participants to get acquainted with the block's specific procedure, 72 experimental trials were performed (24 trials per target, in random order). The experiment took about one hour in total.

All trials followed the same procedure: Participants first moved with their index finger to the starting location as prompted on the computer screen. Once the Leader (individual training) or both Leader and Follower (joint conditions) were in the start location, the Leader's side of the computer screen displayed the target location and a short tone was played (80 ms, 659 Hz). The Leader now moved to the target at her own speed. Upon target arrival, which was detected by online evaluation of the real-time motion tracking data, a second short tone was played. Its frequency depended on the respective condition: In Individual, Vision and None, the same tone was played for all targets (659 Hz). In Pitch, the frequency varied for the three targets (1109 Hz for the first target, 1319 Hz for the second target, 1661 Hz for the third target). The Follower's task was to then perform a speeded hand movement from her own starting location to the same target as the Leader. Subsequently, the screen would turn green or red (for 300 ms), indicating whether Leader and Follower had moved to matching or non-matching targets, respectively. After an inter-trial interval of 700 ms, the next trial began.

In all blocks, Leaders were instructed to not touch the target locations directly and instead end their movements at a point slightly above the table. This was done to prevent any noise when Leaders hit a target which could potentially give directional auditory cues to Followers. Followers were instructed to touch the targets directly.

Data preparation and analysis

From Leaders' movement time series, three time intervals were extracted. 'Time-to-target' (TT) was defined as the interval between the computer-generated start tone and Leaders' movement offset, i.e. the moment when they reached a target position (offset criterion based on the measured calibration points: horizontally inside a radius of 0.8 cm / 1.6 cm / 2.4 cm and vertically below 1 cm). 'Movement onset' (MO) was defined as the interval between the computer-generated start sound and the Leaders' movement onset (onset criterion based on the measured calibration points: horizontally outside of a 2.4 cm radius or vertically above 1 cm), while 'movement time' (MT) was defined as the interval between Leaders' movement onset and offset. Thus, TT equaled the sum of MO and MT. All trials in which Leaders moved to the wrong target or in which TT exceeded two standard deviations around the mean were excluded per Leader and condition from further analysis (4.1 % of all data).

From the remaining trials, we calculated signal-to-noise ratios (SNR) as measures for Leaders' signal clarity. Specifically, the SNR of TT combines the difference between the mean TTs for the three different targets and the variability of these TTs. Thereby, it captures in one measure how distinct Leaders' timing (= signal) is in relation to its variability (= noise). SNR was calculated for each participant and each condition as the averaged difference between mean TTs for adjacent targets, divided by the overall standard deviation of all TTs (across targets), as described by the equation

$$SNR_{TT} = \frac{((M(TT_{tg2}) - M(TT_{tg1})) + (M(TT_{tg3}) - M(TT_{tg2}))) / 2}{SD(TT_{\text{all targets}})}$$

where M designates the mean, SD the standard deviation, and tg1 to tg3 refer to the three target locations. Higher SNR values indicate a clearer signal. In order to test which part of the movement was modulated, we calculated a SNR not only for TT (SNR_{TT}) but correspondingly also for MO (SNR_{MO}) and MT (SNR_{MT}).

For the analysis of movement velocity, we first filtered all trajectories using a 4^{th}-order Butterworth digital filter with cut-off at 10 Hz and then calculated Leaders' mean velocity along the horizontal axis on which the targets were aligned. Finally, to assess joint task performance, trials in which Followers moved to the same target as the Leaders were classified as a match and when they moved to a different target as a mismatch. Based on this, a percentage of target matches per total number of trials was calculated. All data preparation was done with Matlab 2015a and significance testing with IBM SPSS 22.

Results

Modulation of action duration

To investigate whether Leaders adapted their action performance to inform Followers about the target location, we first compared the signal-to-noise ratio for the overall time-to-target (SNR_{TT}; corresponding to the complete interval between the two tones) in the three joint conditions. As predicted, the SNR_{TT} was significantly higher in None (2.33) compared to Vision (.86), $t(11) = 4.89$, $p < .001$, Cohen's $d = 2.95$, and Pitch (1.04), $t(11) = 4.71$, $p < .001$, Cohen's $d = 2.84$. This indicates that Leaders provided a clearer (i.e. more distinct and more consistent) signal when Followers did not have other means to determine to which target they should move.

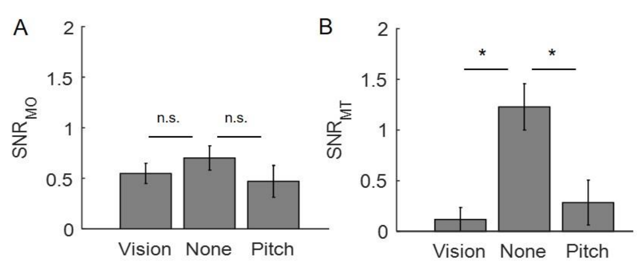

Figure 2: Results of the signal-to-noise ratio analysis for A: movement onset (SNR_{MO}) and B: movement time (SNR_{MT}). Error bars show the standard error.

In a next step, we performed the same analyses separately for Leaders' signal-to-noise ratios of the movement onset (SNR_{MO}) and the movement time (SNR_{MT}) to determine whether they rather chose to wait longer before moving or to slow down their movements. For SNR_{MO} (Figure 2A), None (.7) was not significantly different from Vision (.55), $t(11) = 1.36$, $p > .2$, Cohen's $d = .82$, or from Pitch (.47), $t(11) = 1.25$, $p > .2$, Cohen's $d = .75$. In contrast, for SNR_{MT} (Figure 2B), None (1.23) was significantly larger than Vision (.12), $t(11) = 5.89$, $p < .001$, Cohen's $d = 3.55$, and also than Pitch (.28), $t(11) = 4.55$, $p < .001$, Cohen's $d = 2.75$. Thus, Leaders adapted the execution part of their movements to provide a communicative signal instead of waiting longer before initiating the movement.

Violation of Fitts' law

Given that Leaders chose to provide a communicative signal by changing their movement time, we tested the follow-up hypothesis that they would do so by moving with constant mean velocity irrespective of the target location, which would effectively create a violation of Fitts' law. To this end, we compared Leaders' movement times and mean velocities in None to baseline performance acquired from Leaders' individual training, for which, based on previous research, we expected Fitts' law to hold. Accordingly, we conducted within-subjects ANOVAs to test whether there were significant interactions of the factors condition (Individual, None) and target (first, second, third).

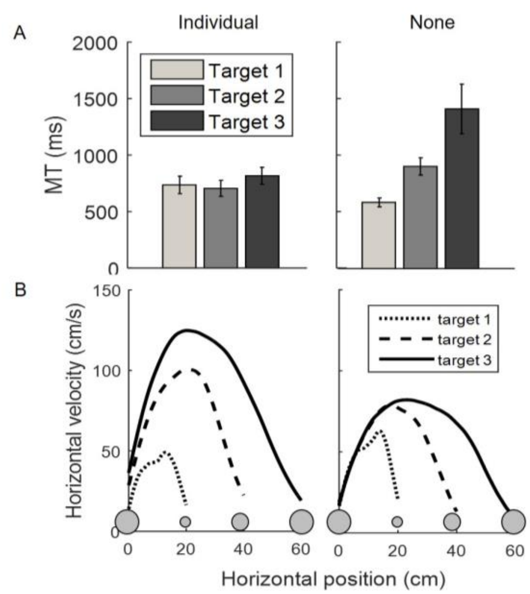

Figure 3: A: Movement times and B: time-normalized grand-average velocity profiles in Individual and None conditions, shown separately for each target.

In line with our predictions, there was a significant interaction of condition and target for movement time (Figure 3A), $F(2,22) = 11.76$, $p < .01$, $\eta_p^2 = .52$, indicating that MT was more strongly influenced by the target position in None than in Individual. There was also a main effect of target, $F(2,22) = 14.92$, $p < .001$, $\eta_p^2 = .57$, and a close-to-significant effect of condition, $F(1,11) = 4.66$, $p = .054$, $\eta_p^2 = .3$.

The analysis of mean velocity (Figure 3B) showed a corresponding pattern of results, suggesting that Leaders indeed created duration differences between targets. In particular, there was a significant interaction effect of condition and target, $F(2,22) = 16.46$, $p < .001$, $\eta_p^2 = .6$, as well as main effects for target, $F(2,22) = 33.4$, $p < .001$, $\eta_p^2 = .75$, and condition, $F(1,11) = 5.03$, $p < .05$, $\eta_p^2 = .31$. Further separate one-way ANOVAs for each condition confirmed that velocity was significantly different for the three targets in the individual baseline, $F(2,22) = 52.06$, $p < .001$, $\eta_p^2 = .83$ (all pair-wise comparisons $p < .001$), but not for None, $F(2,22) = 3.07$, $p > .07$, $\eta_p^2 = .22$ (all pair-wise comparisons $p > .2$).

Joint task performance

Finally, we analyzed the effects that Leaders' signaling performance had on the joint task accuracy, i.e. on how well Followers understood the communicative signal and moved to the correct target location. An analysis of the percentage of target matches showed that dyads' performance suffered from the lack of immediately available perceptual information: Dyads had significantly fewer target matches in None (63.1 %) than in Vision (94.1 %), $t(11) = -6.87$, $p < .001$, Cohen's $d = -4.14$, or Pitch (80.4 %), $t(11) = -3.87$, $p < .01$, Cohen's $d = -2.33$.

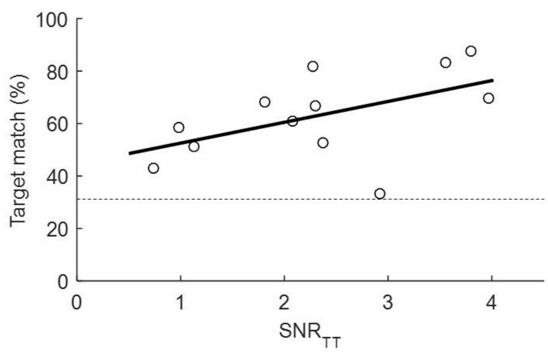

Figure 4: Leaders' signaling behavior as indicated by the signal-to-noise ratio of time-to-target (SNR_{TT}) plotted against dyads' joint performance, i.e. how well Followers managed to move to the corresponding target. The dotted line shows chance performance at 33%.

In the next step, we tested whether those dyads whose Leader provided a better signal in the None condition also succeeded better in moving to the same target locations. To achieve this we correlated pairs' percentage of target match with Leader's signal-to-noise ratio of the overall time-to-target, expecting a positive correlation of the two. Although the correlation (Figure 4) did not reach significance, $r = .521$, $p = .08$, the rather high correlation coefficient suggests a relationship between how good a Leader signals and how well a Follower understands and uses the given information.

Discussion

To increase our understanding of how communication based on instrumental actions is created and used, the present study investigated whether movement duration provides a basis for establishing communication between a Leader and a Follower in a joint action. In our task, Leaders performed movements to target locations unknown to Followers who then attempted to quickly move to the same target location. Crucially, by adjusting target sizes and distances according to Fitts' law (Fitts, 1954), we effectively created a situation in which information could not be transmitted directly via the visual or auditory modality and where established communication systems could not be used. We hypothesized that Leaders would create a new communication system by modulating movement duration to inform Followers and that Followers would be able to use this information to choose which location to move to.

In line with our predictions, we found that Leaders modulated the duration of their movements to indicate different target locations but only if the Follower had no direct visual or pitch information about their actions. This finding demonstrates the specificity of Leaders' communication to contexts in which receiving information was relevant for the joint action partner (Wilson & Sperber, 2004). The present study extends previous work on signaling in interaction contexts that highlighted the role of spatial movement parameters (Pezzulo et al., 2013; Sacheli et al. 2013; Vesper & Richardson, 2014) by demonstrating that movement duration provides a further potential communication channel. Possibly, both producing and understanding communicative signals with action duration is based on motor simulation processes (Wolpert et al., 2003) in which differences between internally predicted and actual action duration would be taken as communicative deviations from natural performance.

Our task was designed such that Leaders had two options of modulating movement duration – either by waiting longer before initiating their movement or by slowing down the movement. The results show that Leaders chose the latter option. This is important for two reasons: First, this result supports the idea that signaling is based on generating predictions and exaggerating aspects of motor performance to allow another person to distinguish between action alternatives. Rather than strategically delaying action onset, Leaders' ongoing actions were systematically sped up or slowed down, although the Follower could not perceive the movements themselves. Second, informing Followers required Leaders to accept a violation of Fitts' law for their own movement execution in order to create distinguishable action durations. An analysis of the velocity profile of Leaders' movements confirmed this by showing that Leaders kept their mean velocity to all targets constant, although the targets greatly differed in size. In fact, keeping velocity constant across targets may have been the most straightforward way to create distinct movement durations for different target locations.

Successful communication presupposes that recipients benefit from the information that was communicated. This was clearly the case for the Followers in our experiment who benefitted from the Leaders' communication when trying to match the target location. Although dyads' task accuracy was lower compared to the conditions where explicit visual or pitch information about the target location was available, all pairs except one managed to perform better than chance. Note that the chance performance in one pair is entirely due to a Follower who, throughout the entire interaction, failed to understand signals with a very good signal-to-noise ratio (see Figure 4). Although follow-up studies would be required to characterize good Leaders and Followers, mentalizing and perspective-taking abilities are likely to play an important role as both informing and understanding modulations of movement as a communicative act likely requires taking the partner's task knowledge and access to perceptual information into account (see also Volman, Noordzij, & Toni, 2012).

Were Leaders aware of their signaling strategy? Although we do not have quantitative evidence, it is likely that actors in the present study were indeed aware that they modulated movement duration to communicate target location to Followers. Most Leaders reported during debriefing that they distinguished between different targets by using different movement times. Similarly, Follows were aware of what feature of the Leaders' action they used to decide to which target they would move. However, there is a possibility that awareness is not always necessary to be successful with the type of communication observed here: Because communication is embedded into the execution of a joint action, people may not always realize that they facilitate performance for a partner as long as the partner detects deviations from standard performance and effectively uses the information to achieve the jointly planned outcome.

Taken together, the present study provides evidence that joint action coordination can benefit from communicative modulations that violate predictions about instrumental actions. Generating and perceiving systematic deviations from the predicted duration of a goal directed action was sufficient to enable an effective non-conventionalized form of communication during joint action.

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References

Becchio, C., Sartori, L., Bulgheroni, M. & Castiello, U. (2008). The case of Dr. Jekyll and Mr. Hyde: A kinematic study on social intention. *Consciousness and Cognition, 17*, 557-564.

Brand, R. J., Baldwin, D. A. & Ashburn, L. A. (2002). Evidence for `motionese': modifications in mothers' infant-directed action. *Developmental Science, 5*, 72-83.

Clark, H. H. (1996). *Using language.* Cambridge, England: Cambridge University Press.

Decety, J., & Jeannerod, M. (1995). Mentally simulated movements in virtual reality: Does Fitts' law hold in motor imagery? *Behavioral Brain Research, 72*, 127–134.

Fitts, P. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, 47*, 381-391.

Graf, M., Reitzner, B., Corves, C., Casile, A., Giese, M. & Prinz, W. (2007). Predicting point-light actions in real-time. *NeuroImage, 36*, T22–T32.

Grosjean, M., Shiffrar, M., & Knoblich, G. (2007). Fitt's law holds in action perception. *Psychological Science, 18*, 95-99.

Pezzulo, G., Donnarumma, F. & Dindo, H. (2013). Human Sensorimotor Communication: A Theory of Signaling in Online Social Interactions. PLoS ONE, 8, e79876.

Sacheli, L., Tidoni, E., Pavone, E., Aglioti, S. & Candidi, M. (2013). Kinematics fingerprints of leader and follower role-taking during cooperative joint actions. *Experimental Brain Research, 226*, 473-486.

Sartori, L., Becchio, C., & Castiello, U. (2011). Cues to intention: the role of movement information. *Cognition, 119*, 242–252.

Scott-Phillips, T. C. (2015). *Speaking Our Minds.* Palgrave Macmillan.

Sparenberg, P., Springer, A. & Prinz, W. (2011). Predicting others' actions: evidence for a constant time delay in action simulation. *Psychological Research, 76*, 41-49.

Umiltà, M. A., Kohler, E., Gallese, V., Fogassi, L., Fadiga, L., Keysers, C. & Rizzolatti, G. (2001). "I know what you are doing": a neurophysiological study. *Neuron, 32*, 91-101.

Volman, I., Noordzij, M. L. & Toni, I. (2012). Sources of variability in human communicative skills. *Frontiers in Human Neuroscience, 6*, 310.

Vesper, C. & Richardson, M. (2014). Strategic communication and behavioral coupling in asymmetric joint action. *Experimental Brain Research, 232*, 2945-2956.

Vesper, C., van der Wel, R. P. R. D., Knoblich, G., & Sebanz, N. (2013). Are you ready to jump? Predictive mechanisms in interpersonal coordination. *Journal of Experimental Psychology: Human Perception and Performance, 39*(1), 48-61.

Wilson, D., & Sperber, D. (2004). Relevance Theory. In Horn, L.R. & Ward, G. (eds.) *The Handbook of Pragmatics.* Oxford: Blackwell, 607-632.

Wilson, M., & Knoblich, G. (2005). The case for motor involvement in perceiving conspecifics. *Psychological Bulletin, 131*(3), 460–473.

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.