

Research Article

PREDICTING THE EFFECTS OF ACTIONS: Interactions of Perception and Action

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Abstract—Many theories in cognitive psychology assume that perception and action systems are clearly separated from the cognitive system. Other theories suggest that important cognitive functions reside in the interactions between these systems. One consequence of the latter claim is that the action system may contribute to predicting the future consequences of currently perceived actions. In particular, such predictions might be more accurate when one observes one's own actions than when one observes another person's actions, because in the former case the system that plans the action is the same system that contributes to predicting the action's effects. In the present study, participants ($N = 104$) watched video clips displaying either themselves or somebody else throwing a dart at a target board and predicted the dart's landing position. The predictions were more accurate when participants watched themselves acting. This result provides evidence for the claim that perceptual input can be linked with the action system to predict future outcomes of actions.

Predicting the effects of actions is a very frequent activity in everyday life. For instance, a person who is driving a car and sees that somebody is crossing the street up ahead will usually predict whether the person will have crossed before the car reaches him or her, in order to decide whether it is necessary to hit the brakes. Similarly, people watching a soccer game willingly predict whether a kick will hit the goal or not. Our aim in the present study was to investigate whether the action system contributes to predicting future consequences of currently perceived actions in situations like these. If this is the case, then one might be better able to predict action effects when one observes one's own rather than another person's actions. This is because the same system that was involved in planning the action is also involved in predicting the effects of the currently observed action. In order to provide a theoretical context for our experiment, we start with a short overview of some theoretical positions on interactions between perception and action.

INTERACTIONS OF PERCEPTION AND ACTION

In many theories of cognitive psychology, the problems of perception and action are treated as being logically independent (Gibson, 1979). It is assumed that perception recovers several objective quantities, like shape, color, and motion, to pass on a general-purpose description of a scene to the cognitive system (Marr, 1982). The action system is regarded as being governed by the cognitive system, executing its commands (Meyer & Kieras, 1997). As a consequence, cognitive processing is conceptualized as being largely independent from perception and action (e.g., Fig. 1.2 in Anderson & Lebiere, 1998). Other theories, however, claim that there are close interactions be-

tween perception and action. In fact, some of these theories hold that many cognitive functions can only be appropriately described as arising from these interactions.

According to Gibson's (1979) ecological approach, perception does not consist of a serial transformation of input. Rather, it is claimed that optical distributions entail different types of information that can be directly perceived. For instance, when an observer walks through an otherwise static environment, optic flow patterns provide information about the direction of the movement or the distance from a certain location. But as soon as the observer stops moving, motion-based information cannot be derived anymore. Hence, perception and action are inseparable in the sense that action enriches the informational content of optical distributions.

Close interactions between perception and action are also postulated by the motor theory of speech perception (Liberman & Mattingly, 1985; Liberman & Whalen, 2000). In fact, this theory suggests that the perception and production of phonetic information are "two sides of the same coin," because the speaker's intended phonetic gestures are the objects of speech production and speech perception. More specifically, representations encoding invariant characteristics of the production of a phonetic gesture determine the articulator's movements when that gesture is produced. In speech perception, the same representations allow the listener to detect the intended speech gestures of the speaker by attempting to resynthesize the perceived gesture. Hence, perception and action are inseparable, as they are both determined by the same representations of intended phonetic gestures.

The common-coding theory (Hommel, Müsseler, Aschersleben, & Prinz, in press; Prinz, 1997) states that the parity between perception and action is not restricted to the linguistic domain (see also Kandel, Orliaguet, & Viviani, 2000; Kerzel & Bekkering, 2000). The core assumption is that actions are coded in terms of the perceivable effects they should generate. Moreover, it is assumed that the representations of intended action effects determine action production and action perception. In action production, the actual movement is determined by representations coding action effects. In action perception, the same representations allow one to detect the intended action goals. Recent evidence from research in neuroscience shows that common coding may occur at the level of single neurons in the brain (Rizzolatti & Arbib, 1998). Gallese, Fadiga, Fogassi, and Rizzolatti (1996) discovered mirror neurons in area M5 in the premotor cortex of the macaque monkey that fire not only when the monkey grasps an object, but also when the monkey is merely watching the experimenter do the same thing. The mirror system embodies exactly the kind of perception-action matching system that common-coding theory predicts. Furthermore, functional magnetic resonance imaging studies provide evidence for the existence of such a system in humans (Decety & Grèzes, 1999; Iacoboni et al., 1999).

A strong case for action-perception interactions in the nonlinguistic domain is made by Viviani and Stucchi's studies (1989, 1992). These authors investigated perceptual judgments for movements that result in end-point trajectories, like drawing and writing. Geometric

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and kinematic properties of such trajectories were misjudged when they violated a motor rule for human motion (the two-thirds power law; Lacquaniti, Terzuolo, & Viviani, 1983), but the judgments were quite accurate when the trajectories complied with this rule. These results support the assumption that the action system is also involved in the perception of biological motion. In a recent study, Kandel et al. (2000) investigated whether the two-thirds power law also influences the ability to predict the future course of a handwriting trajectory. They found that the predictions were most accurate for trajectories that complied with the law and became less accurate the more trajectories deviated from it. Hence, the prediction of action effects was influenced by a motor rule.

PARITY AND DISTINGUISHING BETWEEN FIRST- AND THIRD-PERSON INFORMATION

One problem with the parity argument is that first-person and third-person information cannot be distinguished on a common-coding level. This is because the activation of a common code can result either from one's own intention to produce a certain action effect (first person) or from observing somebody else producing the same effect (third person). Hence, there ought to be cognitive structures that, in addition, keep first- and third-person information apart (Jeannerod, 1999). Otherwise, one would automatically mimic every action one observes. One solution to this problem is provided by Barresi and Moore's (1996) theory of intentional schemas. According to this theory, different types of intentional schemas allow one to link first-person and third-person information more flexibly. Each intentional schema provides a link between one source of first-person information and one source of third-person information. Different schemas process either current or imagined information of either source. Research in the area of motor imagery provides behavioral and neurophysiological evidence for their claim that while imagining actions one uses the same system that governs the actual action production (Annett, 1995; Decety, 1996; Jeannerod, 1994; Wohlschlaeger & Wohlschlaeger, 1998).

As regards action perception, the configuration of first- and third-person information most relevant for our purposes is the current-imagined schema. To derive the intended end of an observed action, this schema links the perceived information (third person) with imagined information about one's own actions (first person). Hence, the schema allows one to derive the intended action effects by imagining oneself producing an action that would achieve the same effects. Because the schema structures the different information sources, neither first- and third-person information nor imagined and perceived information is confused. It is also easy to see that the process of imagining oneself acting does not necessarily have to end when the perceptual input becomes unavailable. Therefore, such a process might allow one to predict future action effects even if the perceptual input becomes unavailable after some time.

In Barresi and Moore's (1996) framework, current information about someone else's actions, in the perceptual input, might also be directly coupled to one's current actions by way of the current-current schema. For instance, when one is watching somebody else look in a certain direction, the current-current schema allows one to direct one's own gaze to the same position or object the other person is looking at, thus coupling one's own attention with that of somebody else (joint attention; Butterworth, 1991). Hence, the current-imagined schema is not invoked obligatorily. Rather, it is only one important means to create a link between perception and action.

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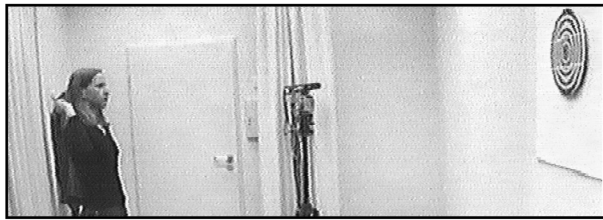
The motor theory of speech perception, the common-coding theory, and the theory of intentional schemas all assume that the action system plays a major role in perceiving actions and predicting their future effects. One way to test this assumption is to look at the perception of self- and other-generated actions. When one is perceiving one's own actions, for instance on a video recording, the same system is involved in producing and perceiving the action. When one is perceiving somebody else's actions, the systems involved in producing and perceiving the action are different. As a consequence, one should be able to recognize one's own actions, at least if common representations linking perception and action retain individual characteristics of a person's actions (e.g., spatial and temporal characteristics of the intended action effects). Several earlier studies provide evidence for this claim. Beardsworth and Buckner (1981) found that their participants better recognized themselves from moving point light displays (Johansson, 1973) than they recognized their friends. In a recent study, Knoblich and Prinz (2001) found that self-generated trajectories of drawing could be recognized, on the basis of kinematic cues. There is also evidence that individuals can recognize their own clapping (Repp, 1987).

Not only should self-recognition be better than other-recognition, but the prediction of future action effects should be more accurate when based on the observation of one's own action than when based on the observation of another person's action. The purpose of the present study, therefore, was to investigate this hypothesis. In our experiment, individuals observed videos that showed a reduced side view of a person throwing a dart at three different regions on a target board (upper, middle, and lower third; see Fig. 1). Only the throwing action was visible; the trajectory and landing on any given throw were not shown. The task was to predict the landing position of the dart on the board. The information provided in the display was varied (head and body, body only, arm only; see Fig. 1). We state our predictions for the different conditions in terms of the intentional-schema theory.

As mentioned earlier, the current-imagined schema links the actions of a person one is currently observing to actions one is imagining at the same time. If the match between the observed and the imagined action is closer for self-generated than for other-generated actions—as we expect—observing one's own throwing actions should allow one to predict the dart's landing position more accurately than observing somebody else's throwing actions. This is because the same system that was involved in planning the action is also used to predict the effects of the currently observed action.

The current-current schema links the current perceptual input about somebody else's actions to one's current actions. The functioning of this schema can be assessed by comparing conditions that vary in the amount of information provided about where the people in the videos directed their attention while aiming. If this schema helps the observer to couple his or her attention to that of the person observed, predicting the dart's landing position should be more accurate when the dart thrower's head and eyes are visible than when they are not (see Figs. 1a and 1b). The reason is that head posture and gaze direction provide cues about the locus of attention.

Because it is quite unusual to watch oneself from a third-person perspective, watching one's own throwing actions might be like watching somebody else's throwing actions, initially. In other words, during an initial phase, participants might rely on third-person information exclusively to generate their predictions about the darts' land-



(a) Group 1: Vision of head and body



(b) Group 2: Vision of body



(c) Group 3: Vision of arm

Fig. 1. Sample frames illustrating the display in the three experimental conditions: head and body visible (a), body visible (b), and arm visible (c).

ing positions. As eye-head information is of this type, it should enter into the prediction of landing position right away. The situation is different for the predicted self-advantage. In this case, the third-person information provided in the display has to be integrated with the first-person information that is imagined (one's own imagined action). This integration may take some time, especially because the perspective is unfamiliar. Therefore, the self-advantage may become visible in later trials only. In order to assess such effects, we divided the experiment into two blocks of equal length.

A further condition was included to determine whether the expected self-other difference is also found when only minimal dynamic

cues are present. In this condition, the participants could base their predictions only on the movement of the throwing arm (see Fig. 1c).

Method

Participants

A total of 104 participants (61 female) recruited by advertising at the University of Munich, Munich, Germany, and in local newspapers took part in the experiment. All participants were paid. They ranged in age from 19 to 40 years. All were right-handed and had normal or corrected-to-normal vision. Nobody was a dart expert, but all participants knew the game and had played it once in a while before. Participants were assigned to three experimental groups (see Fig. 1). Group 1 ($n = 28$) judged displays in which body and head were visible. Group 2 ($n = 34$) judged displays with body visible and head invisible. Group 3 ($n = 42$) judged displays in which only the throwing arm was visible.

Materials and procedure

There were two sessions separated by at least 1 week. At the first session, we collected the raw material from which the stimuli for Session 2 were prepared. We began with a dart-throwing training session. Participants threw darts at a board divided into thirds of equal height (as shown in Fig. 1). One third of the board was declared the target (e.g., upper third). As soon as a participant scored five consecutive hits within the target third, he or she proceeded to the next third (e.g., lower third), until all thirds were covered. After the training, the video recording began, and the participant was filmed from a lateral perspective while throwing. The video showed the participant on the far left and the target board on the far right of the picture. Again, each third of the target board, consecutively, was declared the target. Fifteen clips showing hits were recorded for each third.

In the next step, the raw video material from each participant was edited, and the experimental videotapes (one for each participant) were prepared (Video Machine equipment by FAST, Munich, Germany). Each clip started with the participant picking up the dart. It ended right before the dart left the participant's hand; that is, the trajectory and landing of the dart were omitted. Out of the 15 clips for each third of the target board for each participant, 10 were selected. Hence, there were 30 different clips for each participant, displaying 10 different throws that had hit the upper, middle, and lower third of the target board. From these clips, we prepared a video presenting two blocks of 60 throws each. Hence, each original clip was displayed twice in a block. Within each block, clips displaying throws that had landed in the different thirds were arranged randomly. After each clip, a homogeneous blue display was shown for 7 s to provide sufficient time for responding and preparing for the next trial.

In the second session, each participant watched two videotapes. One displayed the throwing actions of the participant him- or herself, and the other displayed the throwing actions of another person. The participants were organized into pairs. Participant A watched video A (self) first and then video B (other). Participant B also watched video A (other) first and then video B (self). That is, 2 participants watched exactly the same stimulus materials in the same order, and the order of watching oneself or the other person first was counterbalanced. The task was to predict after each clip whether the dart had been propelled to the upper, middle, or lower third of the board. The responses were given verbally and were recorded by the experimenter. Participants in

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all conditions knew whether they watched themselves or somebody else.

Results

The raw judgments were converted into d' sensitivity measures (Macmillan & Creelman, 1991). In a first step, two different d' values were computed: one for the ability to correctly predict whether the dart hit the upper or the middle third of the target board and one for the ability to correctly predict whether the dart hit the lower or middle third of the target board. Because there were no significant differences between the two measures, they were averaged. The resulting d' measure indicates the ability to correctly predict whether the dart landed in one of two adjacent thirds. The left, middle, and right panels in Figure 2 show the results for Groups 1, 2, and 3, respectively.

Participants in all groups were able to predict the landing position of the dart after watching a throwing action. The predictions were most accurate for Group 1 (head and body visible, mean $d' = 0.79$), less accurate for Group 2 (body visible, mean $d' = 0.60$), and least accurate for Group 3 (arm visible, mean $d' = 0.48$). Hence, the accuracy of predictions was lower when fewer body parts were visible. Overall, there were virtually no differences in the accuracy of prediction for self- and other-generated throwing actions during the initial half of the trials (mean $d' = 0.59$ for self-generated actions, mean $d' = 0.57$ for other-generated actions). For Group 3, however, there was a slight advantage for self-generated actions during the first block (mean $d' = 0.47$ for self-generated actions, mean $d' = 0.39$ for other-generated actions). During the second half of the trials, the predictions were more accurate for self-generated than for other-generated actions in all experimental groups (mean $d' = 0.74$ for self-generated actions, mean $d' = 0.60$ for other-generated actions).

The d' values were entered into a $3 \times 2 \times 2$ analysis of variance with the between-subjects factor of group (body and head visible,

body visible, arm visible) and within-subjects factors of authorship (self vs. other) and half (first vs. second). There was a significant main effect for group, $F(2, 101) = 6.51, p < .01$; t tests showed that the predictions of Group 1 were significantly more accurate than those of Group 2 ($p < .05$), whereas Groups 2 and 3 did not differ significantly ($p = .14$). Further, there was a significant main effect of half, $F(1, 101) = 11.72, p < .001$; predictions were better during the second than the first half of trials. The main effect of authorship was only marginally significant, $F(1, 101) = 2.9, p = .09$. Also, there was a significant interaction between half and authorship, $F(1, 101) = 7.91, p < .01$. Cohen's f was computed as a size-of-effect measure for this effect using the GPOWER software (Erdfelder, Faul, & Buchner, 1996). The resulting f was 0.28. Hence, the effect size is medium, according to Cohen's (1988) taxonomy. Additional t tests showed that during the second half of trials, predictions were more accurate for self-generated actions than for other-generated actions in Groups 1 ($p < .05$), 2 ($p < .01$), and 3 ($p < .05$). None of the other interactions were significant (all $ps > .10$).

The pattern of results for Group 3 slightly differs from that of Groups 1 and 2 (see Fig. 2, right panel). Numerically, there was a difference between self- and other-generated actions during the first half, and the accuracy of predictions for other-generated actions increased from the first to the second half. The results of t tests showed that neither the first nor the second difference was statistically significant (both $ps = .15$).

DISCUSSION

Observing throwing actions allowed the participants to predict a dart's landing position. Predictions were more accurate when the head and eyes of the acting person were visible in addition to his or her body and arm. This result supports the assumption that one's own attention can be coupled with that of another person (Adamson & Bake-



Fig. 2. Accuracy of prediction for self- and other-generated action during the first and the second half of trials. Results are shown separately for the three experimental groups.

man, 1991; Barresi & Moore, 1996; Butterworth, 1991) to predict forthcoming actions and their effects. Such a coupling could be provided by the current-current schema that links the currently perceived eye and head position to the observer's action (eye movement) system.

In later trials, the predictions were more accurate when participants observed their own throwing actions than when they observed another person's throwing actions. This self-advantage cannot be due to differences in the stimulus displays, because pairs of participants watched exactly the same displays (see Method). Neither can differential effects of error feedback explain the effect, as no error feedback was given. Rather, the result is consistent with the assumption that the current-imagined schema links actions one is observing (third-person information) to actions one is imagining concurrently (first-person information; Barresi & Moore, 1996) to predict forthcoming action effects. The observation of a self-generated action is then more informative, because the observed action pattern was produced by the same system that also imagines the action (Knoblich & Prinz, 2001). As regards the initial lack of the self-other difference, the most likely explanation is that observers tend to initially rely on third-person information, such as head or body posture, even when they observe themselves. The self-other difference occurs only later because it depends on the integration of the first-person information (the imagined action) with the third-person information in the display (the observed action), and this integration takes time. This interpretation would also explain why the self-advantage occurred somewhat earlier in Group 3 than in the other groups. Group 3 judged the displays that provided the smallest amount of third-person information (i.e., the arm-visible condition). Because less third-person information was present, integration occurred faster.

In the present study, all participants were informed about whether they were seeing themselves or another person. This raises the question whether this knowledge is a necessary condition to obtain the self-advantage. A recent study investigating the prediction of strokes in writing trajectories showed that the self-advantage is also present when participants are not explicitly told whether they are watching the products of their own or somebody else's actions (Knoblich, Seigerschmidt, & Prinz, 2000). Interestingly, in that study, the self-other difference occurred from the outset, a result consistent with our interpretation for the initial lack of the self-other difference in the present study. When third-person information is sparse, as in end-point trajectories of drawing, and third- and first-person information can be relatively easily integrated (as the production and observation perspectives are the same), self-other differences occur in early trials.

The results of our study add evidence to an expanding literature in psychology (Ballard, Hayhoe, Pook, & Rao, 1997; Hommel et al., in press; Prinz, 1997) and neurophysiology (Decety & Grèzes, 1999; Gallese et al., 1996; Jeannerod, 1997) suggesting that many cognitive functions reside in interactions between perception and action systems. The theory of intentional schemas (Barresi & Moore, 1996) provides one way to conceptualize such interactions. Similar assumptions lie at the core of the motor theory of speech perception (Liberman & Mattingly, 1985), the common-coding framework (Prinz, 1997), and the notion of a mirror system (Gallese & Goldman, 1998). Recently, Rizzolatti and Arbib (1998) claimed that this system, originally devised for understanding actions, might also have provided the starting point for the evolution of the language faculty in humans. Future research must be conducted to prove the validity of such far-reaching claims.

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