Seeing While Moving:
Measuring the Online Influence of Action on Perception

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Abstract

The online influence of movement production on motion perception was investigated. Participants were asked to move one of their hands in a certain direction while monitoring an independent stimulus motion. The stimulus motion unpredictably deviated in a direction that was either compatible or incompatible with the concurrent movement. Participants' task was to make a speeded response as soon as they detected the deviation. A reversed compatibility effect was obtained: reaction times were slower under compatible conditions, i.e., when motion deviations and movements went in the same direction. This reversal of a commonly observed facilitatory effect can be attributed to the concurrent nature of the perception-action task and to the fact that what was produced was functionally unrelated to what was perceived. Moreover, by employing an online measure, it was possible to minimize the contribution of short-term memory processes, which has potentially confounded the interpretation of related effects.

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Perception and action almost always co-occur in everyday life. Yet, surprisingly little research has investigated how these “two sides” of cognition specifically interact in such situations. The majority of investigations have employed *sequential* paradigms, in which participants are asked to react to the presentation of a stimulus. A well-know example comes from the study of stimulus-response compatibility (SRC), in which it has often been shown that people are faster to respond to a stimulus (e.g., presented to the left) when the required response shares representational features with the stimulus (e.g., a left button press) than when it does not (e.g., a right button press; for reviews see Hommel & Prinz, 1997; Proctor & Reeve, 1990). As reflected in this example, the typical finding in SRC research is that compatible stimulus-response relations lead to a performance advantage (but see, e.g., Caessens, Notebaert, Burle, & Soetens, 2005) that is often attributed to a *facilitatory* influence on action-related processes.

In the present study, we investigated how action specifically influences perception in a *concurrent* paradigm, in which what needs to be perceived co-occurs with and is functionally unrelated to the movement that needs to be produced. Unlike what has usually been found in the SRC literature, the results revealed a reversed compatibility effect, in that people were faster to react to stimuli that were incompatible with the concurrently produced movements. Moreover, in contrast to studies that have explored effects related to our own, we minimized the contribution of short-term memory processes on performance by measuring online the influence of action on perception.

As alluded to above, SRC research has normally relied on sequential paradigms. There are nonetheless some interesting exceptions. For example, Chua and Weeks (1997) have reported that people are better at synchronizing their movements with stimulus motions when the endpoints of the movements and motions spatially correspond than when they do not. In related research, it has been shown that visuomotor tracking performance is more stable for in-phase than anti-phase movement-motion relationships (Michaels & Stins, 1997) and that performance in such tasks is further improved by the angular similarity between the movement and motion trajectories (Ehrenstein, Cavonius, & Lewke, 1996). These findings were among the first to demonstrate that feature overlap between stimuli and responses also leads to facilitation effects in more dynamic tasks in which movements are generated during the perception of stimuli.

More recently, a number of studies have turned to the issue that is at the core of the present study, that is how action influences perception in concurrent paradigms. In addition to focusing on perception, these paradigms involve functionally unrelated perceptual and motor events, i.e., the stimuli in no way specify what movements need to be simultaneously produced. Under such conditions, *interference* rather than facilitation effects have generally been obtained (Hamilton, Wolpert, & Frith, 2004; Müsseler & Hommel, 1997; Schubö, Aschersleben, & Prinz, 2001; but see Wohlschläger, 2000). In a task in which participants were asked to observe sinusoidal motions of a dot while producing sinusoidal hand trajectories, Schubö et al. (2001) found that produced amplitudes had a repulsive (or contrastive) effect on perceived amplitudes. For example, medium-amplitude motions were perceived as smaller when observed during the generation of large- rather than medium-amplitude movements. Along similar lines, Hamilton et al. (2004) have shown that the perceived weight of identical-looking boxes lifted by others is repulsed by simultaneously held weights: boxes were judged as heavier when observed while lifting light as opposed to heavy weights.

An issue that none of these studies has fully addressed is the contribution of short-term memory processes. This issue merits further attention because it is known that compatibility effects of this type are influenced by such processes. For example, when Schubö, Prinz, and Aschersleben (2004) increased the interval between the presentation of the stimulus motions and the assessment of how participants had perceived them, the contrast effect obtained by Schubö et al. (2001) turned into an assimilation effect (i.e., an attraction of produced on perceived amplitudes). It has also been shown that action production can have an assimilatory effect on visual short-term memory. Kerzel (2001) asked participants to first observe stimulus motions that could vary in velocity, then produce a fast or slow movement, and subsequently judge the velocity of the previously seen motion. The results revealed that the remembered velocities were biased in the direction of produced velocities.

In all of the paradigms considered until now, perceptual judgments were always provided without speed stress and after the movement and motions were completed. It is therefore unclear if and in what way action-based influences on short-term memory, rather than on perception, might have contributed to the observed effects (for a similar argument in context of research on inattentional blindness, see Moore, Grosjean, & Lleras, 2003). In light of this, we sought to minimize the influence of short-term memory processes by investigating the *online* influence of action on perception. The term “online” is used here to refer to the fact that perceptual performance was assessed under speed stress and while the stimulus motion was still in progress.

The second objective of this study was to determine whether action would facilitate or interfere with perception. This was of particular interest because we employed the overlapping perception-action dimension of direction, which has typically led to facilitation (or assimilation) effects in both sequential and concurrent paradigms (see above). Thus, if evidence of interference (e.g., contrast) is obtained, it would suggest that either the influence of action on perception differs qualitatively from the influence of perception on action and/or that the nature of the influence depends on the mutual functional (un)relatedness of perception and action in the paradigm in question.

To address these issues, we asked participants to perform hand movements either to the left or right while monitoring the motion of a stimulus. In most trials, the stimulus moved vertically before unpredictably deviating to the left or right. The task of the participants was to press a button with their non-moving hand as soon as they detected a deviation in stimulus motion away from vertical. The direction of the deviation was either compatible with the hand movement direction (e.g., both went to the right) or incompatible. If action facilitates (i.e., has an assimilatory influence on) perception, reaction times should be shorter under compatible than incompatible conditions. Conversely, if action interferes with perception, as indicated by the repulsion effects obtained by Hamilton et al. (2004) and Schubö et al. (2001), this reaction-time pattern should be reversed.

Method

Participants

Sixteen right-handed individuals (age range 21-31 years) were paid for their participation. None of the participants reported any visual or motor impairments, and they were all naive as to the purpose of the study.

Stimuli, Movements, and Apparatus

The stimulus motions consisted of a red circle (6 mm in diameter) that moved on a black background without leaving a trace. The length and duration of the motions were 20 cm and 1000 ms, respectively. The motions always started from a position that was horizontally centred and shifted 10 cm below the horizontal midline of a 21” monitor. As Figure 1 illustrates, the motions followed one of nine trajectories with equal probability:

straight upwards without changing direction, straight upwards before deviating 5° to the left or right at 0, 250, 500, or 750 ms after motion onset. The circle subtended 0.57° of visual angle and moved at a constant speed of 18.92 °/s at the approximate viewing distance of 60 cm. To indicate the moment at which they perceived a change in stimulus motion direction, participants pressed a button on a custom-made response box with their left index finger.

Figure 1 about here

A graphics tablet (Wacom Ultrapad A3E) was used to record the movements of a hand-held stylus at a sampling rate of 70 Hz. The tablet was placed directly below and centred with respect to the monitor, and was covered by a board to prevent participants from seeing their hand. The required movements consisted of 20 cm straight-line trajectories that were directed 45° to left or right of the participants' body midline. Movements were always performed with the right hand and the response box was operated with the left hand.

Design

Movement direction (left, right), deviation direction (DD; left, right) and direction deviation time (DDT; 0, 250, 500, 750 ms) were manipulated within participants. Movement direction was blocked and counterbalanced across participants, with each movement direction being performed for eight consecutive blocks. In each block, all eight DD x DDT combinations + one catch trial (in which no motion deviation occurred) appeared twice in a pseudorandom order. This amounted to a total of 288 trials.

Procedure

Prior to the first block and then every other block, participants practiced the leftward or rightward hand movements with the help of a display that depicted the required and actually produced trajectories. This feedback display was only provided between practice trials.

In the experimental blocks, the task of the participants was to press a button on the response box as soon as they detected a stimulus motion that deviated from vertical while concurrently performing the required movement. Each trial began with the presentation of a small white cursor that represented on-line and 1:1 the position of the stylus on the graphics tablet. To initiate the rest of the trial and assure that participants always started their movements from the same location, they first had to move the cursor within the stimulus (i.e., the red circle) which appeared at its start position (see Figure 1). One second later, a tone (1760 Hz, 15 ms) signalled that they could start moving whenever they felt ready. As soon as the stylus left the start position (i.e., moved out of the area defined by the red circle), the cursor disappeared, the stimulus was set into motion, and movement recording began. A 1000 ms later, the onset of a second tone (880 Hz, 15 ms) signalled to the participants that they should still be moving (the required movement times were between 1 and 2 s). The display was cleared at this point if it had not already been cleared by a button press. Movement recording lasted for another 1000 ms. At the end of the recording phase (i.e., 2000 ms after movement/motion onset) a third tone was played (440 Hz, 15 ms). If participants lifted the pen, reversed movement direction, or pressed the button less than 150 ms or more than 1000 ms after the DDT, an error message to that effect was shown. The next trial started after a 1000 ms interval.

Data Analysis

Tangential velocity profiles were computed via numerical derivation of the movement trajectories. Movement onset/offset was defined as the first moment in time at which tangential velocity reached/dropped below 5% of peak tangential velocity prior to/after the peak. The angle and length of the movements was determined between movement onset and offset. Reaction Time (RT) was measured relative to DDT.

Catch trials were not analyzed. Moreover, in order to only include trials with acceptable hand movements, trials were excluded when one of the following hierarchical criteria was met: (a) the stylus was moved after the third tone (i.e., 2000 ms after movement onset; late movement), (b) the stylus was lifted during movement (lift), (c) participants reversed the direction of drawing (reversal), (d) the angle of the movement deviated by more than 20° from the required angle or the length of the movement was shorter than 10 cm (trajectory failure). Trials were also discarded when RTs were shorter than 150 ms (anticipation) or longer than 1500 ms (miss).

To establish the influence of produced movement direction on perceived motion direction, trials were classified as *compatible* when movement and motion deviation directions corresponded (e.g., both were leftward) or as *incompatible* when they did not. Mean RTs were then submitted to a two-way repeated-measures ANOVA with Compatibility (compatible, incompatible) and DDT (0, 250, 500, 750 ms) as within-participant factors. When necessary, violations of sphericity were corrected for using the Greenhouse-Geisser ε.

Results

The mean percentages of excluded trials were 0.27%, 1.49%, 0.95%, 0.59%, 3.49%, 3.98% for late movements, lifts, reversals, trajectory failures, anticipations, and misses, respectively, resulting in a total of 10.77% discarded trials.

Produced Movements

Figure 2 shows the required and mean produced trajectories for left and right movement directions. To produce this figure, each movement trajectory was initially time normalized. This was done by resampling the horizontal and vertical coordinates for each trajectory at 101 (0-100%) equally spaced time points. The coordinates at these time points were subsequently averaged across trials and participants (for details see, e.g., Spivey, Grosjean, & Knoblich, 2005). As can be seen in the figure, the produced movements nicely approximated the required movements. The mean movement times, absolute end angles, and lengths were 1194 ms, and 1112 ms, 42.55°, 44.53°, 21.03 cm, and 20.57 cm for the left and right directions, respectively.

Figure 2 about here

Reaction Times

Table 1 presents mean RT as a function of DDT and compatibility. As can be seen, RTs decreased with DDT. More importantly, RTs were higher for compatible than incompatible conditions and the size of this compatibility effect decreased with DDT (see Figure 3). In support of these observations, there was a significant main effect of DDT ($F(3, 45) = 234.74$, $MSE = 7020$, $p < .001$), Compatibility ($F(1, 15) = 17.79$, $MSE = 1346$, $p < .01$), and a significant interaction between these two factors ($F(3, 45) = 9.29$, $MSE = 1133$, $p < .01$). The 95% confidence intervals in Figure 3 reveal that the compatibility effect was significant at DDTs of 0 and 250 ms, but not thereafter.

Table 1 about here

Figure 3 about here

Anticipations and Misses

Table 1 also contains the percentage of anticipations and misses. When the same ANOVA as above was performed on these measures, no evidence of any speed-accuracy tradeoffs involving the factor Compatibility was obtained.

Discussion

The findings of the present study demonstrate that produced movement directions interfere with concurrently perceived motion directions. Specifically, a reversed compatibility effect was obtained: motion deviations were detected later when they went in a direction that was compatible with that of the movements. By employing an online measure, the current results also go beyond existing ones (e.g., Hamilton et al., 2004; Müsseler & Hommel, 1997; Schubö et al., 2001) by showing that interference of this type occurs during perceptual processing, as opposed to in short-term memory. Mean RT in the 0 ms DDT condition was 880 ms, which indicates that most detection responses in this condition were provided prior to motion offset (i.e., at 1000 ms). Thus, the contribution of short-term memory processes to the reversed compatibility effect was at a minimum. Moreover, the observation that the compatibility effect decreased with DDT further supports the notion that movement production had an online influence on perceptual processing. Indeed, the later the motion deviation occurred, the smaller the amount of temporal overlap between the movement and the motion deviation. There was consequently less time for the produced movement direction to interfere with the perception of the new motion direction at longer DDTs.

Until now, compatibility was always defined in terms of the relationship between the direction of the produced movements (left or right) and the direction in which the stimulus motions deviated from vertical (DD: left or right). Recall, however, that participants always performed the movements with their right hand and operated the response box with their left hand. This could have lead to an additional source of compatibility between DD and the (location of the) hand used for measuring RTs. If this were the case, then one would expect an asymmetry in the size of the reversed compatibility effect for DDs to the left and right. To test this, mean RTs were submitted to an additional ANOVA with DD and Compatibility (defined in the same way as above) as within-participant factors. Although this analysis revealed a main effect of DD ($F(1, 15) = 14.96$, $MSE = 11729$, $p < .01$), reflecting that DDs to the left were detected on average ~30 ms later than DDs to the right, DD did not interact with the factor Compatibility ($F < 1$). Thus, the reversed compatibility effect obtained here was not modulated by the location of the hand operating the response box.

One account of the reversed compatibility effect is that perceived directions were repulsed by produced directions, which led to a delay in detecting the moment at which the compatible motions deviated from vertical. As proposed by Schubö et al. (2001) and Hamilton et al. (2004), this repulsion (contrast) effect may arise from the inhibition/occupation of common codes/modules employed by perception and action. For example, according to Schubö et al. (2001), movement production and motion perception rely on the distributed activation of a common set of codes along certain dimensions, such as direction (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1990). When what is produced resembles what is perceived, as under compatible conditions in the present study, a certain number of activated codes will overlap for perception and action. To minimize the amount of interference that could thereby be incurred, these overlapping codes are assumed to become inhibited. Thus, when the movement and motion deviation are both directed to the right, for example, some “rightward” codes will no longer contribute to motion perception, which has the effect of shifting the perceived direction to the left. In order to explain the decrease in the size of the reversed compatibility effect with DDT, one would have to further assume that the amount of repulsion is proportional to the amount of temporal overlap between movement production and motion perception.

An alternative account of the reversed compatibility effect is that incompatible motion deviations were detected faster than compatible ones because the former were more at odds with action-specific sensory predictions generated by forward models in the motor system. Miall et al. (2006) adopted this idea to explain a set of related findings. They asked people to produce a sequence of hand gestures while concurrently watching an independent sequence of hand images that was either congruent or incongruent with the produced gestures. People’s task was then to detect oddball hand images that diverged from the image sequence. The results revealed that oddballs were detected faster when they were presented in a sequence of images that were congruent with the produced gestures, which suggests that people are better at perceiving events that diverge from their action-based anticipations. Moreover, this effect was short lived in that it disappeared when a 500 ms delay was inserted between successive displays. Although their paradigm and effect differ markedly from our own, one could nonetheless apply a similar logic to the present findings. Based on our results, however, it is impossible to determine whether this account or the repulsion-type accounts of Schubö et al. (2001) and Hamilton et al. (2004) is/are more applicable in the present context.

A result that was not considered until now was that overall mean RTs decreased with DDT, whereas error rates had a tendency to increase with DDT, at least for the 750 ms DDT.

Although the increase in error rates may simply reflect a form of speed-accuracy tradeoff, there are at least three alternative, and non-mutually exclusive, explanations for the decrease in RTs. First, as is typically observed in paradigms with variable foreperiods between warning and imperative stimuli (in our case, motion onset and deviation onset, respectively), RTs decrease with the amount of unspecific preparation (e.g., Niemi & Näätänen, 1981). However, foreperiod effects are typically much smaller than the RT decrease observed here and are not typically accompanied by an increase in error rates. According to the second explanation, the amount of dual-task-like interference (e.g., Pashler, 1994) was reduced for longer DDTs because motions and/or movements were already completed at the time of responding. Finally, it is known that more attentional resources are required for initiating hand movements (e.g., Posner & Keele, 1969), and therefore less resources may have been available for the detection task at shorter DDTs.

The growing number of reports of contrast effects in concurrent paradigms suggests that the typically observed facilitation (or assimilation) effects are reversed when what is produced is functionally unrelated to what is simultaneously perceived. However, the mere change in focus from perception on action to action on perception cannot account for the reversal of the effect. For example, Schubö et al. (2001) reported a contrast effect of perception on action as well: produced movement amplitudes were repulsed by perceived motion amplitudes (see above for a description of their paradigm). This indicates that the nature of perception-action interactions varies as function of whether what is perceived is informative or not with respect to what needs to be produced. In the former case, the goal is to employ the results of perception to trigger or guide movement production. In the later case, the goal is to minimize the interference between perception and ongoing action.

References

Caessens, B., Notebaert, W., Burle, B., & Soetens, E. (2005). Voluntary and involuntary control over automatic processing in spatial congruency tasks: Editors' introduction. *European Journal of Cognitive Psychology*, *17*(5), 577–589.

Chua, R., & Weeks, D. J. (1997). Dynamical explorations of compatibility in perception-action coupling. In B. Hommel & W. Prinz (Eds.), *Theoretical issues in stimulus-response compatibility* (pp. 373–398). Amsterdam: North-Holland.

Ehrenstein, W. H., Cavonius, C. R., & Lewke, E. (1996). Spatial visuo-motor compatibility and manual control in a tracking task. In K. A. Brookhuis, C. Weikert, & C. R. Cavonius (Eds.), *Human factors in training and simulation* (pp. 12–22). Groningen: Traffic Research Center, VSC, University of Groningen.

Hamilton, A., Wolpert, D., & Frith, U. (2004). Your own action influences how you perceive another person's action. *Current Biology*, *14*(6), 493–498.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (2001). The Theory of Event Coding (TEC): A framework for perception and action planning. *Behavioral & Brain Sciences*, *24*(5), 849-937.

Hommel, B., & Prinz, W. (Eds.). (1997). *Theoretical issues in stimulus-response compatibility*. Amsterdam: North-Holland.

Kerzel, D. (2001). Visual short-term memory is influenced by haptic perception. *Journal of Experimental Psychology: Learning Memory and Cognition*, *27*(4), 1101–1109.

Miall, R. C., Stanley, J., Todhunter, S., Levick, C., Lindo, S., & Miall, J. D. (2006). Performing hand actions assists the visual discrimination of similar hand postures. *Neuropsychologia*, *44*(6), 966–976.

Michaels, C. F., & Stins, J. F. (1997). An ecological approach to stimulus-response compatibility. In B. Hommel & W. Prinz (Eds.), *Theoretical issues in stimulus-response compatibility* (pp. 333–360). Amsterdam: Elsevier Science.

Moore, C. M., Grosjean, M., & Lleras, A. (2003). Using inattentional blindness as an operational definition of unattended: The case of perceptual completion. *Visual Cognition*, *10*(3), 299–318.

Müsseler, J., & Hommel, B. (1997). Blindness to response-compatible stimuli. *Journal of Experimental Psychology: Human Perception and Performance*, *23*(3), 861-872.

Niemi, P., & Näätänen, R. (1981). Foreperiod and simple reaction time. *Psychological Bulletin*, *89*(1), 133-162.

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin*, *116*(2), 220–244.

Posner, M., & Keele, S. (1969). Attention demands of movements. In *Proceedings of the XVI. international congress of applied psychology.* Amsterdam: Swets & Zeitlinger.

Prinz, W. (1990). A common coding approach to perception and action. In O. Neumann & W. Prinz (Eds.), *Relationships between perception and action: Current approaches* (pp. 167–201). New York: Springer. Proctor, R. W., & Reeve, T. G. (Eds.). (1990). *Stimulus-response compatibility: An integrated perspective*. Amsterdam: North-Holland.

Schubö, A., Aschersleben, G., & Prinz, W. (2001). Interactions between perception and action in a reaction task with overlapping S-R assignments. *Psychological Research / Psychologische Forschung*, *65*(3), 145-157.

Schubö, A., Prinz, W., & Aschersleben, G. (2004). Perceiving while acting: Action affects perception. *Psychological Research / Psychologische Forschung*, *68*(4), 208–215.

Spivey, M. J., Grosjean, M., & Knoblich, G. (2005). Continuous attraction toward phonological competitors. *Proceedings of the National Academy of Sciences of the United States of America*, *102*(29), 10393–10398.

Wohlschläger, A. (2000). Visual motion priming by invisible actions. *Vision Research*, *40*(8), 925-930.

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