# A Simon effect induced by induced motion and location: Evidence for a direct linkage of cognitive and motor maps

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It has been argued that two distinct maps of visual space are formed: a cognitive map that is susceptible to illusions, and a motor map that represents the physical world veridically. In the present study, subjects responded to a nonspatial attribute of a visual target stimulus by pressing a left or right key, while an illusory horizontal displacement of the target was induced. A Simon-type effect was obtained to the induced target motion or position shift—that is, responses were faster when the illusory target motion or location corresponded to the response position. Further experiments indicated that the observed effects cannot be accounted for by attentional shifts. These results suggest that the content of the cognitive map does not only influence perceptual judgments but is also responsible for the automatic activation of response codes. In other words, perception and action seem to be fed by a common, cognitively penetrable, spatial representation.

In the literature, a distinction has been made between two separate visual pathways: a (more or less) nonspatial "what" path and a spatial "where" path (e.g., Bridgeman, Peery, & Anand, 1997; Goodale & Milner, 1992). It has been assumed that these two pathways serve different functions: One is concerned with what is generally considered as "visual perception," whereas the other feeds directly into action control. Two lines of evidence support this view.

First, Goodale, Milner, Jakobson, and Carey (1991) tested a patient with lesions in the ventral stream of projections from the striate cortex to the inferotemporal cortex. Despite a pronounced disorder in the perception of object features, such as form, orientation, and size, this patient showed accurate guidance of hand and finger movements toward objects. According to the authors, this finding suggests that different neural substrates underlie visual object perception on the one hand and the use of object information for the control of manual movement on the other.

Second, Bridgeman and colleagues (Bridgeman, Kirch, & Sperling, 1981; Bridgeman, Lewis, Heit, & Nagle, 1979; Bridgeman et al., 1997) obtained perceptual and motor measures of illusory (or real) target displacement from healthy subjects. Using either induced motion (Bridgeman et al., 1981; see Figure 1) or the Roelofs effect (Bridgeman et al., 1997; see Figure 4), the authors demonstrated a dissociation between these measures: Subjects' performance was less affected by the visual illusion when they pointed toward the target than when they indicated the target's position by means of a perceptual adjustment procedure. Bridgeman et al. (1997) argue that two distinct maps of visual space are formed: a *cognitive* map and a *motor* map. Whereas the former is susceptible to illusions, the latter is not supposed to be susceptible to illusions, but rather to represent the physical world in a more or less veridical fashion. The content of the cognitive map is accessed in the course of explicit retrieval of spatial information, as required in spatial judgments, whereas the content of the motor map is assumed not to enter awareness and to directly control spatial responses, such as pointing.

A different view on dissociations between motor and perceptual tasks was proposed by Smeets and Brenner (1995). They pointed out that in the study of Bridgeman et al. (1981), the perception of an (apparently moving) object's *velocity* was compared with a motor response to a
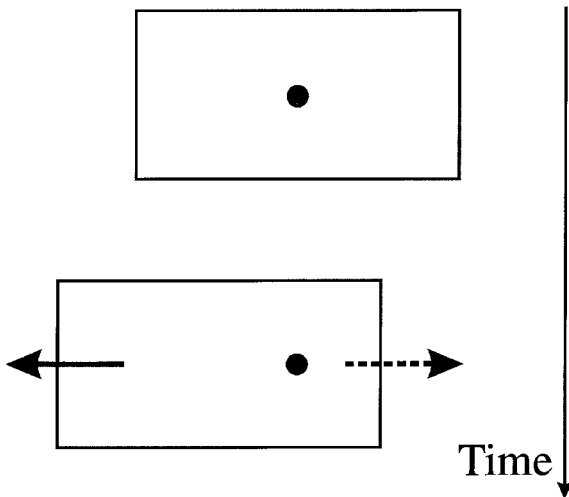
**Figure 1. When a frame surrounding an object is shifted horizontally, the stationary object inside the frame appears to move in the direction opposite to the real motion. Illusory and real motion are indicated by dotted and solid lines, respectively. The illusory motion of the object is referred to as induced motion. It can be observed with abrupt displacements of the frame and with smooth motion of the frame. With abrupt motion, the frame is shown in two different positions only (as in the figure). With smooth motion, the number of frame positions that are presented is higher, and the spatial distance between successive frame positions is smaller, so that the impression of a continuous motion is elicited.**

*position*. In their own study, Smeets and Brenner found that velocity information was perturbed not only in perceptual tasks but also in motor tasks, whereas position information was veridical in both perceptual and motor tasks, which accounts for the accurate pointing performance in Bridgeman's experiments. Thus, Smeets and Brenner's results suggest that the same sources of information are used in perception and action.

## Stimulus–Response Compatibility

Additional evidence for the assumption that perception and action access common spatial maps comes from research on phenomena of spatial stimulus–response (S–R) compatibility (Hommel & Prinz, 1997; Proctor & Reeve, 1990). These phenomena are usually observed if people perform spatially defined responses to stimuli that vary in spatial location. For instance, if left- and right-hand keypresses are performed in response to visual stimuli that randomly appear on the left or right side of a display, performance is better with spatial S–R correspondence (i.e., if the left response is mapped onto the left stimulus and the right response onto the right stimulus) than with noncorrespondence (left response onto right stimulus and right response onto left stimulus; e.g., Broadbent & Gregory, 1965). The advantage of S–R correspondence persists even when spatial attributes of the stimulus are irrelevant to the task. If, for instance, verbal instructions serve as an imperative signal for left–right keypresses, responses are faster if the stimulus appears

on the same side as the response (e.g., Simon, Hinrichs, & Craft, 1970)—an effect that has come to be known as the *Simon* effect (for an overview, see Lu & Proctor, 1995). It is important for the present study that the Simon effect is observed not only with stationary stimuli but with apparently moving stimuli as well; hence, responses are faster if the stimulus appears to move toward the side at which it is located (Michaels, 1988; Proctor, Van Zandt, Lu, & Weeks, 1993).

The most widely accepted explanation of both the spatial compatibility effect proper and the Simon effect is in terms of stimulus and response coding (e.g., Kornblum, Hasbroucq, & Osman, 1990; Prinz, 1990; Wallace, 1971). Following Wallace (1971), it is assumed that stimuli and responses are represented by more or less binary spatial (left–right) codes. When, in a given trial, the spatial stimulus and response codes correspond, this facilitates S–R translation and speeds up the response, whereas noncorresponding codes lead to a response conflict because the incorrect response code is erroneously activated. In fact, electrophysiological studies have shown that presenting a stimulus in a Simon-type task more or less automatically induces response-related activation in the spatially corresponding hand, such as lateralized readiness potentials (De Jong, Liang, & Lauber, 1994; Eimer, 1995; Sommer, Leuthold, & Hermanutz, 1993) or subthreshold electromyographical potentials (Zachay, 1991). This suggests that the codes of spatial stimuli and responses overlap, which again implies that perception and action operate on the same spatial maps (Rizzolatti, Riggio, & Sheliga, 1994).

## Aim of the Study

The purpose of the present study was to investigate the apparent contradiction between the demonstrations of a close relationship between spatial perception and space-based action on the one hand and Bridgeman and colleagues' notion of a strict separation of cognitive and motor spatial maps on the other. To do so, we used stimulus displays that are likely to induce visual illusions of the type investigated by Bridgeman and colleagues, and we tested whether these displays would produce effects of S–R compatibility or, more precisely, Simon-type effects.

In our experiments, the relevant stimulus was a patch that mostly appeared and stayed at screen center. The subjects had to respond either to the color or to the shape of the object. A frame surrounding the target moved to the left or right, a condition that is known to yield the impression of stationary objects moving in the opposite direction (Duncker, 1929). Like in a typical Simon task, the subjects responded to a stimulus dimension that is orthogonal to the induced change in position with a left or right response. However, whether or not one would expect a Simon effect to occur depends on one's preconception of whether visual perception and motor action rely on common spatial maps.

According to the approach of Bridgeman et al. (1979), one would expect that the objective, not yet cognitively

interpreted stimulus information is directly delivered to the motor system. Since there is no reason why this information should be differentially coded in terms of left and right (i.e., all stimuli appear at exactly the same location), there is no basis for a Simon effect; hence, the speed and accuracy of left and right responses should not vary with the direction of the visual context or the illusory perception of target motion. However, if perception and action access the same source of spatial information, one would expect both to be biased in the same way. In the present task, this would mean that the response system is subject to the same illusion as the perceptual system. Accordingly, left responses should be faster with a right-moving visual background—because this induces illusionary target motion to the left—whereas right responses should be faster with a left-moving background.

## EXPERIMENT 1

In Experiment 1, we examined whether a Simon effect can be demonstrated with stimuli that, according to Bridgeman and colleagues, should have distinct motor and cognitive representations. We used displays suitable for evoking induced motion that are similar to those of Bridgeman et al. (1981): While responding to a stationary target on a screen, the subjects were presented with a visual background rectangle that jumped to the left or right (see Figure 1). Such a display induces illusory displacement of the target in the opposite direction—that is, a leftward displacement of the target is perceived with a rightward displacement of the rectangle, and vice versa. If, and only if, the response system underlies the same illusion as the perceptual system, performance should depend on background motion, so that spatial correspondence between induced displacement and response location would produce better performance than would noncorrespondence.

However, an alternative interpretation of a Simon effect to induced displacement is possible. Stoffer (1991) claimed that a spatial compatibility effect is observed if, and only if, the last step in attentional focusing of the stimulus is a shift in attention and that it is the direction of this shift that determines the spatial stimulus code's content. Although Stoffer's own findings are open to alternative interpretations (Hommel, 1993) and are difficult to replicate (Weeks, Chua, & Hamblin, 1996), it might be worthwhile to pursue this line of thought. Suppose that the real motion of the background pattern captured the subjects' attention in such a way as to induce a shift of the attentional focus in the pattern's direction. Thus, when the target stimulus comes up, an attentional shift back to the target is required (for a similar line of reasoning in another context, see Rubichi, Nicoletti, Iani, & Umiltà, 1997). According to Stoffer's approach, this would lead to the spatial coding of the target stimulus as "left" with a rightward displacement of the rectangle and as "right" with a leftward displacement. If so, it may not be the correspondence between the response and the in-

duced displacement that produces the compatibility effect but rather the correspondence between the response and the location of the stimulus relative to the focus of attention at the time of target presentation.

One implication of this basic idea is that the temporal relationship between frame displacement and stimulus presentation should play a role. If the frame is displaced before the stimulus color is presented, a shift back to the stimulus would be more plausible than if the displacement occurs simultaneously with or after color presentation. Consequently, if effects of correspondence between induced displacement and response location are obtained, they should be more pronounced the longer the displacement of the inducing context precedes the presentation of the stimulus. To test whether this is the case, we varied the stimulus-displacement onset asynchrony (SDOA). With negative SDOAs, the displacement occured 98 or 196 msec before the critical stimulus feature was presented (i.e., before the stimulus changed to red or green). With zero SDOA, the context was displaced at the same time the stimulus was presented. With positive SDOAs, the context frame was displaced 98 or 196 msec after the stimulus color had appeared.

### Method

**Subjects**. Twenty-six adults were paid to participate in single sessions of about 30 min. They reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment.

**Apparatus and Stimuli**. Stimulus presentation and data acquisition were controlled by a Hewlett Packard Vectra PC, interfaced with an Eizo MD-B11 graphics adaptor and attached to an Eizo Flexscan monitor (9070S or 9080i). The subjects responded by pressing the left or right shift key of the computer keyboard with the corresponding index finger. The target stimulus was an elliptical patch of 0.5° in width and 0.6° in height. It always appeared first in white at the center of the black screen and changed then to red or green, the response-relevant stimulus colors, without changing its location. The reference object was a white, 1-pixel thick frame of 6.7° in width and 4.3° in height. It always appeared first in the center of the screen, symmetrically surrounding the target stimulus, and was then shifted 2.9° to the left or right, to induce a displacement of the target to the right or left, respectively. The frame shift was realized between two screen-refresh cycles by means of video-page switching.

**Design**. The subjects worked through 20 experimental blocks, preceded by a single practice block. Each block was composed of the possible combinations of 2 target colors (or response locations), 2 directions of frame displacement, and 5 SDOAs, randomly intermixed. Half of the subjects responded to red and green target objects by pressing the left and right response key, respectively, whereas the other half received the opposite color–key mapping.

**Procedure**. The experiment took place in a dimly lit room. Viewing distance was about 60 cm. After an intertrial interval of 500 msec, each trial started with the presentation of the stimulus (in white color), surrounded by the reference frame, for 1,500 msec. In the nonpositive conditions, the frame was then shifted to the left or right, followed by a color change to red or green of the target stimulus after 196, 98, or 0 msec. In positive SDOA conditions, the target's color change came first, followed by the frame shift after 98 or 196 msec. The display stayed until the response, but no longer than 1,000 msec. Responses that took longer were omitted. If the response was incorrect or omitted, an auditory error feedback was given, and the trial was recorded and repeated at some random po-
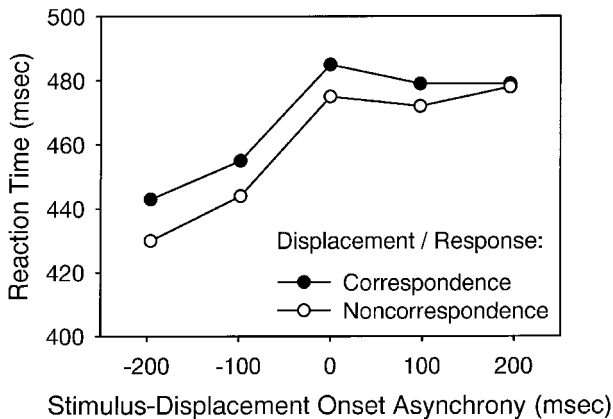
**Figure 2. Reaction times as a function of correspondence and stimulus-displacement onset asynchrony in Experiment 1. In corresponding trials, the direction of frame displacement and the response location were congruent, so that the direction of induced motion and the response location were incongruent. The reverse was true in noncorresponding trials.**

sition in the remainder of the block. After the first half of the experimental trials, the subjects were given the opportunity to take a rest.

## Results

Trials with response omissions (0.5%) were excluded from analysis. Mean reaction times (RTs) and percentages of error (PEs) were computed as a function of SDOA, response location, and frame displacement. As shown in Figure 2, RT varied with SDOA [$F(4,100) = 42.70$, $p < .001$] due to quicker responses with negative SDOAs than with the other SDOAs. More importantly, there was a significant interaction of frame displacement and response location [$F(1,25) = 4.54$, $p < .05$]. Left responses were faster when the frame was displaced to the right (i.e., when the target seemed to move to the left) than when the frame moved to the left (460 vs. 470 msec); the opposite was true for right responses (466 vs. 459 msec). Although this effect decreased from negative to positive SDOAs, the interaction was far from significant ($p < .3$). In contrast to RTs, the error rates decreased from negative to positive SDOAs (4.4%, 5.6%, 3.5%, 2.4%, and 2.1%, for SDOAs of $-196$, $-98$, 0, +98, and +196 msec, respectively) [$F(4,100) = 9.12$, $p < .001$], indicating a speed–accuracy tradeoff associated with SDOA. Yet, analogously to RTs, an interaction of response location and frame displacement was observed [$F(1,25) = 7.08$, $p < .05$], independent of SDOA ($p > .3$). When left responses were made in the presence of a frame that was shifted to the right (i.e., when the target seemed to move to the left), less errors were made than with a left-moving frame (2.8% vs. 3.9%), whereas the opposite was true for right responses (4.6% vs. 3.1%).

## Discussion

Responses to a stationary colored stimulus were faster when this stimulus apparently moved in a direction that corresponded to the location of the correct response location. Obviously, then, manual choice RT is affected by illusory target motion in the same way as perception. If we assume, following Bridgeman and colleagues (Bridgeman et al., 1981; Bridgeman et al., 1997), that perception is mediated by a cognitive map and that action is controlled by a motor map, such an outcome suggests that motor responses are not performed independently of contents of the cognitive map but rather are more or less directly affected by them. Given that neither the real motion of the background texture nor the apparent motion of the target were relevant to the task, we can further assume that this interaction between cognitive and motor maps is relatively automatic. Furthermore, the lack of a correspondence × SDOA interaction is evidence against an explanation of the effect in terms of attentional shifts. If the frame had automatically captured attention, requiring a shift back toward the stimulus, the correspondence effect should have been more pronounced with negative SDOAs than with zero or positive SDOAs; yet, there was no reliable evidence that the Simon effect was affected by the temporal relationship between frame displacement and stimulus presentation. Even the unreliable drop of the correspondence effect with the longest positive SDOA was most likely due to rather trivial reasons: Given that stimulus localization can be affected only by context information available before localization is completed, there must be some SDOA level where context effects are no longer observed.

## EXPERIMENT 2

The results of Experiment 1 indicate that illusory features of a stationary stimulus have access to the motor map. Moreover, the lack of a correspondence × SDOA interaction suggests that the frame did not attract attention in the direction of its displacement. However, the latter conclusion rests on a null effect; therefore, it seemed necessary to gather converging evidence to support it, which is what we did in Experiments 2 and 3. In Experiment 2, an attempt was made to diagnose possible frame-induced attention shifts in a relatively direct way. The display conditions were very similar to those of Experiment 1, but the choice reaction was replaced by a detection response. Each trial began as in Experiment 1, but the white circle did not change color. Instead, some time after the frame moved, another unfilled circle appeared in 75% of the trials; this unfilled circle was to be responded to with a simple keypress. This target stimulus could appear at the center, surrounding the stationary filled circle, or on the left or right. The predictions are straightforward: If displacing the frame would induce a shift of attention in the same direction, responses to the target should always be fastest if it appears at the center of the frame; hence, if it appears on the left after leftward displacement of the frame and on the right after rightward displacement. However, if displacing the frame would not induce attention shifts, responses should not depend
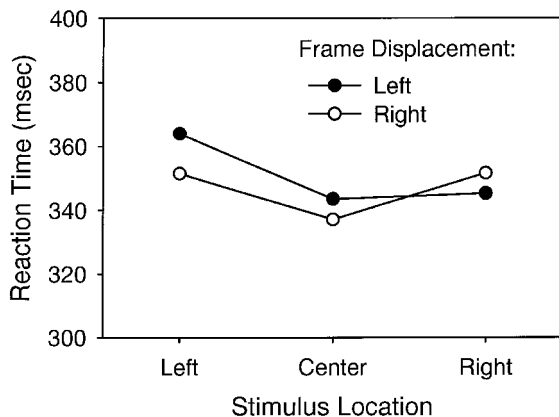
**Figure 3. Reaction times as a function of stimulus location and frame displacement in Experiment 2.**

on frame direction but should always be fastest with central target presentation.

## Method

Eight adults were paid to participate. The method was the same as that in Experiment 1, with the following exceptions. The white patch shown within the white frame at the beginning of each trial was somewhat smaller (0.3° × 0.4°) and stayed white until the end of the trial. After the frame was displaced to the left or right and a randomly determined interval of 50–350 msec had passed, a bright white 1-pixel-thick elliptical frame of 0.8° × 1.2° appeared for 100 msec in 75% of the trials. It surrounded the white patch or was displaced 3.0° to the left or right of it (center to center) in 25% of the trials. If the unfilled circle appeared, the subjects were to press a microswitch mounted on a board in front of them; however, if the circle was not presented, they were to refrain from responding.

The subjects worked through 15 test blocks, preceded by one practice block. Each block consisted of two replications of each of the eight possible combinations of 2 directions of frame displacement and 4 stimulus conditions (3 locations + 1 absent trial); hence, there were 30 replications of each condition. Responses that took 100 msec or less were considered anticipatory and were repeated within a block.

## Results

Performance in no-go trials was nearly perfect, with no anticipatory reactions and only very few false alarms (i.e., in-time keypresses; 0.6%). Go trials with response omissions (0.4%) or anticipatory reactions (0.2%) were excluded from analysis. Mean RTs are shown in Figure 3. A two-way analysis of variance (ANOVA) of frame direction × stimulus location produced a significant main effect of stimulus location [$F(2,14) = 8.10$, $p < .005$]. As confirmed by Newman–Keuls post hoc comparisons ($p < .05$), responses were slower with left-side stimulus presentation (358 msec) than with right-side presentation (348 msec) or central presentation (340 msec). The effect of frame direction was far from significant ($p > .28$), and, most importantly, there was no indication of an interaction ($p > .69$).

## Discussion

The results do not support the idea that a displaced frame draws attention to it. The fastest responses were

observed with central target presentation, and there was no hint of any benefit of spatial alignment of stimulus and frame—if anything, alignment produced worse performance. Together with the outcome of Experiment 1, this implies that stimuli can be spatially coded in the absence of attentional shifts, which provides evidence against an attention-shifting account. Further evidence against this account comes from studies showing that attentional capture by abrupt onsets is not fully automatic but depends on the attentional set of the observer. Theeuwes (1991) and Yantis and Jonides (1990) showed that when attention is spatially focused (e.g., on the imperative circle in Experiment 1), peripheral abrupt onsets no longer capture attention. In addition, work by Folk and his colleagues (e.g., Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994) has shown that, even when attention is not in a focused state, and observers are "set" to respond to color (as in Experiment 1), abrupt onsets do not capture attention.

## EXPERIMENT 3

Experiment 3 was conducted as a further test of possible objections from an attention-shifting perspective. The basic motivation of such a perspective derives from the idea that a quickly displaced frame may capture attention in the same automatic fashion as a stimulus that appears with an abrupt onset in the retinal periphery (e.g., Egeth & Yantis, 1997; Jonides, 1981; Miller, 1989). Although automatic attentional capture may not have occurred in our Experiment 1 because of the subjects' attentional set (see Folk et al., 1992; Folk et al., 1994; Theeuwes, 1991; Yantis & Jonides, 1990), it would be even more convincing if the same effects were observed when automatic attentional capture is unlikely. In this case, there would no longer be a basis for an attention-shifting account. To avoid capture in Experiment 3, we smoothened the motion of the frame. That is, instead of the frame being abruptly displaced, it slowly moved to the left or right. Smooth real motion (of the actual target) has been shown to be ineffective in producing a Simon effect (Ehrenstein, 1994), whereas abrupt motion does yield an effect (Michaels, 1988; Proctor et al., 1993). The main difference between abrupt and smooth motion is the ratio of stimulus velocity and stimulus presentations per time interval (frame rate). For instance, in Proctor et al.'s (1993) Experiment 1, nine frames were presented in 300 msec (frame rate of 33 Hz), and the target moved at a speed of 18.1°/sec, such that the target appeared to jump from one location to the next. In contrast, Ehrenstein (1994) used a much slower velocity of only 2°/sec, which looks rather smooth and "real" even if rendered at a video-refresh rate comparable to that used by Proctor et al.

The absence of a Simon effect to the direction of smooth (target) motion was interpreted as supporting the attention shifting account of the Simon effect. In Ehrenstein's (1994) study, responses were keypresses, and the irrelevant dimension was either the direction of smooth target motion or the target's position. Simon effects were ob-

tained to the horizontal position of a target, but not to its horizontal direction of motion. Ehrenstein argued that variations in stimulus position capture attention, which in turn triggers the planning of saccadic eye movements (Rizzolatti, Riggio, Dascola, & Umiltà, 1987). In contrast, motion at moderate velocity failed to shift attention, so that no Simon effect occurred. The absence of a Simon effect to the direction of smooth motion and its presence for target position were taken as evidence for the view that attentional shifts and the subsequent planning of saccadic eye movements are necessary to produce a Simon effect (e.g., Umiltà & Nicoletti, 1992). Attentional shifts, so it was argued, did not occur with smooth stimulus motion that usually elicits pursuit eye movements, not saccades (Pola & Wyatt, 1980; Westheimer, 1954). Corroborating evidence in favor of this interpretation comes from a study in which small-scale motion failed to automatically attract attention to single items of a visual search display (Hillstrom & Yantis, 1994).

In the present experiment, we sought to clarify whether illusory motion induced by smooth frame displacement yields a Simon effect. If presented in complete darkness, smooth frame motion gives the impression that a stationary target surrounded by the frame smoothly moves in the direction opposite to the actual frame motion (e.g., Mack, Heuer, Fendrich, Vilardi, & Chambers, 1985). As demonstrated by Ehrenstein (1994), smooth motion does not produce Simon-like effects, perhaps because attentional shifts are not elicited. Thus, according to an attention-shifting account, no Simon effect should show up with smooth frame motion, whereas our coding account does not suggest any difference between abrupt displacement and smooth motion: Since induced motion is perceived in both cases, effects of S–R congruence should emerge.

Stimulus and response parameters in the present experiment were chosen to avoid abrupt onsets and to maximize S–R compatibility. Smooth motion was produced by the gradual increase of the frame's velocity from zero. The velocity profile was sinusoidal, and the peak velocity shown was 1.16°/sec—hence, even below the 2°/sec used by Ehrenstein (1994). In order to maximize S–R compatibility, the continuous changes in stimulus position had to be responded to by dynamic stylus responses to the left or right. It is known that similarity between stimuli and responses determines compatibility relations (Greenwald, 1970; Kornblum et al., 1990). The frame shown in the present experiment extended 6° from fixation in both directions, which is comparable to the 5° in Ehrenstein (1994). To ensure that the subjects fixated the target, we used different shapes instead of colors as imperative stimuli. The sizes of imperative figures was such that they were difficult to discriminate if fixation deviated from the screen center.

## Method

**Subjects**. Ten adults were paid to participate in single sessions of about 40 min. They reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment.

**Apparatus and Stimuli**. Stimulus presentation and data acquisition were controlled by a Pentium 166 computer interfaced with a Matrox Millenium graphics adaptor and attached to a Nokia 445xi monitor. The refresh rate was 96 Hz at a pixel resolution of 1,280 × 1,024. The subjects moved a stylus to the left or to the right with the dominant hand. Responses were recorded by a CalComp Drawing Board III with a spatial resolution of 394 lines/cm and a sampling rate of approximately 125 Hz. We approximated stimulus parameters that have been shown to produce induced motion (Mack et al., 1985): A 12° × 3° luminous rectangle was initially symmetrically surrounding the target. The target always appeared in the center of the screen. Frame motion followed a raised sinus function starting at 270° with a frequency of 0.1 Hz and an amplitude of 12°, as opposed to a frequency of 0.05 Hz and an amplitude of 9° in Mack et al. (1985). Amplitude and frequency were higher than in Mack et al., because only a part of the complete cycle was shown. At the longest, the frame motion lasted for 2.1 sec, the velocity of the frame motion being 1.16°/sec at display termination (i.e., after the response had been obtained). This is quite comparable to the peak velocity of 0.85°/sec used by Mack et al. After the frame had moved for a random interval of 0.9 to 1.2 sec (velocities of 0.53°/ sec to 0.69°/sec, respectively), the target turned into a 0.26° unfilled square or circle, and the motion of the frame continued for a maximum of 0.9 sec. The color of the stimuli was dark gray, in order to avoid stray light and afterimages. The background color was black.

**Design**. The subjects worked through 10 experimental blocks. Each block was composed of 5 repetitions of the four possible combinations of 2 target shapes (or response locations) and 2 directions of frame motion. Half of the subjects responded to square and circle target objects by moving the stylus to the left and right, respectively; the other half received the opposite shape–direction mapping.

**Procedure**. The experiment took place in complete darkness. Viewing distance was kept constant by using a chin-head rest. After an intertrial interval of 1 sec, the frame and the target appeared and remained motionless for 1 sec. Then, the smooth motion started. After the imperative signal appeared, the frame and target remained visible for 0.9 sec. At the start of each trial, the subjects had to position the pen on its home position by aligning two objects on the screen that represented pen and home position. Recording from the graphics table started with motion onset and stopped with display termination. A regression technique was used to determine the onset of the response. In a time window of approximately 30 msec (three samples), sample time was regressed onto sample position. The slope (i.e., the velocity) of two consecutive regression windows was determined while the windows were shifted across the complete sample. When the difference between the regression slopes of the two windows (i.e., the velocity difference) surpassed a certain criterion, the intersection of the two regression lines was used as onset. Responses occurring between motion onset and onset of the imperative stimulus and responses with latencies shorter than 100 sec and longer than 900 msec were omitted. If the response was incorrect or omitted, visual feedback informed the subject about the kind of error, and the trial was recorded and repeated at some random position in the remainder of the block. Before the experiment started, responses were practiced with a stationary frame on a gray background. After the first half of the experimental trials, the subjects were given the opportunity to take a rest.

## Results

Trials with response omissions (2%) were excluded from analysis. Mean RTs and PEs were computed as a function of response direction and motion direction. An ANOVA on RT revealed a significant interaction between the two factors [$F(1,9) = 9.45, p < .05$]. When the stylus had to be moved to the left, responses were faster
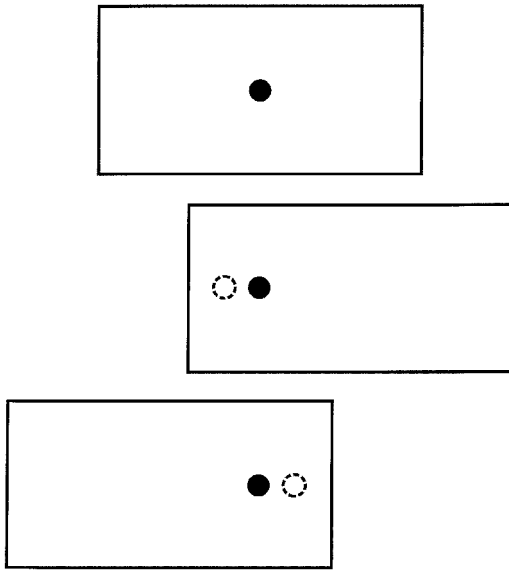
**Figure 4. The Roelofs effect (Roelofs, 1935) is obtained when an object is placed inside a frame that is offset to the left or right. The judged position of the object (dotted circle) deviates from the actual position (filled circle) in the direction opposite to the frame offset.**

when the frame moved to the right (i.e., the target seemed to move to the left) than when it moved to the left (487 vs. 501 msec). The opposite was true for right responses (506 vs. 485 msec), which amounts to a net correspondence effect of 18 msec. An ANOVA on PEs yielded no significant effects. Inspection of the error rates gave no indication of a speed–accuracy tradeoff. With left responses, more errors were made with leftward frame motion than with rightward motion (3.3% vs. 2.5%). The opposite was true with right responses (2.9% vs. 4.8%).

**Discussion**

Again, responses to the stationary target were faster when its illusory motion corresponded to the direction of the response. Similar to the compatibility effect observed with keypresses and abrupt displacements of the inducing stimulus, the correspondence relation between the induced motion of the target and a left–right movement had a reliable effect on RTs. The Simon effect to induced motion with smooth frame motion lends further support to our explanation of the effect in terms of spatial coding and renders an account in terms of attentional shifts unlikely. Because the motion of the frame was smooth, it appears unlikely that attentional shifts were induced by the display; yet, the presence of the Simon effect shows that the stimuli must have been spatially coded. Consequently, spatial coding cannot depend on shifting attention.

It remains to be investigated why Ehrenstein (1994) found no Simon effect to the direction of smooth target motion—an outcome suggesting no spatial coding. We suspect that differences in response mode may explain the discrepancy. Ehrenstein used keypresses, whereas we

used stylus movements as responses. Thus, S–R similarity was higher in our setup, such that S–R correspondence effects were more likely to occur (Greenwald, 1970; Kornblum et al., 1990). Note that the available attentional accounts do not consider similarity between stimulus and response codes as a factor.

In sum, our results suggest that a Simon effect to induced motion may be obtained, and its occurrence cannot be reduced to attentional factors. Rather, stimulus and response codes interacted, suggesting that illusory target features have access to the motor programming stage. Therefore, a strict separation of cognitive and motor maps appears not justified.

**EXPERIMENT 4**

In Experiments 4 and 5, we dealt with a possible objection from a separate-maps perspective that relates to the debate between Bridgeman and colleagues on the one side and Smeets and Brenner on the other. As pointed out by Smeets and Brenner (1995), Bridgeman et al. (1981) compared cognitive judgments about the motion of an object with motor responses to its position. Therefore, the supposed distinction of cognitive and motor maps is confounded with the type of information that subjects had to attend to. And, in fact, Smeets and Brenner demonstrated that when position and velocity were considered separately for cognitive and motor measures, position judgments were accurate regardless of response type, whereas both cognitive and motor measures were susceptible to illusory velocity information. Our present results are consistent with this finding: We observe Simon effects to induced motion using both step-ramp and smooth displacements, suggesting that illusory object motion has direct access to the motor system.

However, in a reply to Smeets and Brenner (1995), Bridgeman et al. (1997) demonstrated that the assumed dissociation of motor and cognitive maps may be obtained for a position-related illusion that is potentially free of motion-induced eye movements. When a target is surrounded by a frame that is displaced to the left or to the right such that the target is in either the left or the right part of the frame, the judged position of the object is influenced by the position of the frame (Figure 4). With left displacement of the frame, the target is judged to be more to the right than it actually is, and vice versa. In other words, locations of targets within the frame tend to be misperceived in the direction opposite to the offset of the frame—the "Roelofs effect" (after Roelofs, 1935). Bridgeman et al. (1997) showed that cognitive measures are influenced by this illusion but not (fast) motor responses. Thus, one may argue that the separation of cognitive and motor maps holds only for postiion, not for velocity. In this case, the (velocity-based) Simon effect to induced motion does not really provide evidence against a separation of cognitive and motor maps. For our argument, it therefore is critical to demonstrate a Simon effect not only for illusory motion but also for misperceived location, as observed in the Roelofs effect.
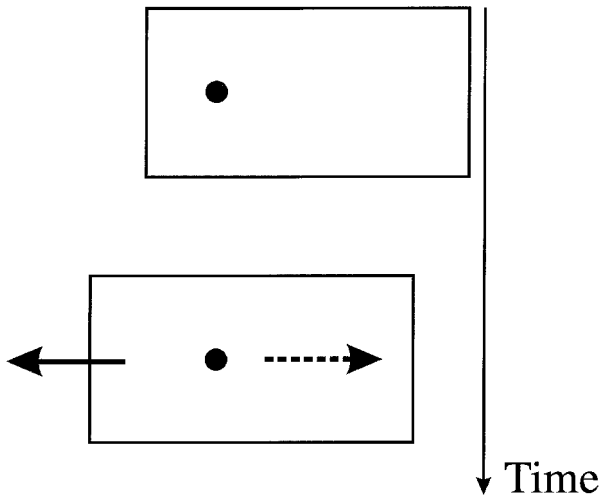
**Figure 5. In Experiment 4, the relative position of the target inside the frame was separated from the direction of induced motion. To this end, the starting position of the target was always in either the left side or the right side of the frame. After the motion of the frame had stopped, the target was still on the same side as at the start of the trial.**

A closer examination of the displays that we used so far reveals that they include a confound. Since the frame was initially centered around the target, the displacement of the frame entailed a shift of the target position to the left or right side of the frame. That is, the frame was offset to the left or right of the target stimulus: With leftward motion of the frame, the direction of illusory motion was to the right and, simultaneously, the illusory location of the target was shifted to the right, and vice versa. Therefore, changes of perceived position attributable to the Roelofs effect were confounded with the direction of induced motion.

Experiments 4 and 5 were designed to disentangle illusory direction of motion and illusory position. In Experiment 4, the position of the frame was changed such that leftward and rightward motion no longer coincided with the induced left–right position of the target. In Experiment 5, no motion was induced, but targets were surrounded by static frames offset to the left and right. If illusory motion—but not location—was crucial for the Simon effect in Experiments 1 and 3, then a compatibility effect should be observed in Experiment 4 but not in Experiment 5. In contrast, if illusory position information—but not motion—was responsible for the compatibility effect in Experiments 1 and 3, then such an effect is expected in Experiment 5 but not in Experiment 4. Of course, it may also be that both motion and location codes can access response stages, which would produce compatibility effects in both experiments.

In Experiment 4, we disentangled the impact of motion and frame-relative position by changing the position of the frame such that the target appeared and stayed on

either the left side or the right side of the frame during a whole trial. This was done by displacing the initial position of the frame by 3° (25% of the frame's horizontal extent) to the left or right (see Figure 5). Since the maximal distance traveled by the frame in Experiment 3 was 1.2°, the target position was in either the left side or the right side of the rectangle, irrespective of where the frame moved. Thus, illusory position information induced by asymmetric frame placement, as in the Roelofs effect, could be separated from illusory target motion induced by smooth displacements of the frame. If illusory position information due to frame placement accounted for the compatibility effects observed in Experiments 1 and 3, no Simon effect to the direction of induced motion would be observed. In contrast, if illusory target motion accounted for these effects, a replication of the results from Experiment 3 would be expected.

### Method

**Subjects**. Eight adults were paid to participate in single sessions of about 40 min. They reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment.

**Apparatus and Stimuli**. The stimuli and the apparatus were the same as those in Experiment 3 with the exception that the frame was displaced by 3° to the left or right side of the center of the screen (the target position). Thus, the frame was asymmetrically spaced around the target. The target was either in the left part of the frame (right displacement) or in the right part (left displacement).

**Design**. The subjects worked through 13 experimental blocks. Each block was composed of 2 repetitions of the four possible combinations of 2 target shapes (or response locations), 2 directions of frame motion, and 2 frame positions (left and right).

**Procedure**. The procedure was the same as that used in Experiment 3.

### Results

Trials with response omissions (5.5%) were excluded from analysis. Mean RTs and PEs were computed as a function of frame placement, response direction, and motion direction (see Table 1). A three-way ANOVA of response direction × motion direction × frame placement on RT revealed a significant interaction of response direction and direction of motion [$F(1,7) = 27.39$, $p < .005$]. Leftward responses were faster with right frame motion (i.e., left induced motion) than with left frame motion (449 vs. 467 msec). The reverse was true with rightward responses (469 vs. 447 msec), yielding a net compatibility effect of 20 msec. Furthermore, frame placement and direction of motion interacted [$F(1,7) = 9.58$, $p < .05$]. Responses in the presence of a frame displaced to the right (i.e., the target was in the left part of the frame) were faster when the frame moved to the right (i.e., the target appeared to move to the left) than when it moved to the left (454 vs. 467 msec). In contrast, when the frame was displaced to the right, responses were faster when the frame moved to the left (451 vs. 461 msec). In a three-way ANOVA on PEs, a significant three-way interaction of response direction, motion direction, and frame displacement emerged [$F(1,8) = 6.44$, $p < .05$]. Inspec-

**Table 1**
**Mean Reaction Times (RT, in Milliseconds) and Percentage of Errors (PE) in Experiment 4 as a Function of Frame Position, Direction of Frame Motion, and Response Location**

| Frame Motion | Frame Position | | | |
|---|---|---|---|---|
| | Left | | Right | |
| | RT | PE | RT | PE |
| *Left Response* | | | | |
| Left | 468 | 2.8 | 467 | 3.3 |
| Right | 457 | 3.3 | 441 | 1.9 |
| *Right Response* | | | | |
| Left | 439 | 5.5 | 456 | 3.3 |
| Right | 477 | 3.7 | 461 | 8.8 |

tion of the error pattern showed no indication of a speed–accuracy tradeoff for the interaction of direction of frame motion and response direction. With leftward responses, more errors were made with leftward frame motion (i.e., induced motion to the right) than with rightward frame motion (3% vs. 2.5%). With rightward responses, more errors were made with rightward frame motion than with leftward frame motion (6.3% vs. 4.4%).

## Discussion

Although illusory motion and location were unconfounded in Experiment 4, we were able to fully replicate the results of Experiment 3. That is, responses were faster when the direction of induced motion and the response direction were congruent. In contrast, response direction did not interact with frame displacement, which suggests that illusory location does not have access to response stages. The only further effect of interest was an interaction of frame position and direction of motion, showing that performance is better if the two spatial parameters of the stimulus are congruent. This effect is in line with other research demonstrating faster processing of stimuli with congruent values defined on perceptual or semantic dimensions (e.g., Melara & Marks, 1990).

## EXPERIMENT 5

In Experiment 4, we did not find a Simon effect to frame-induced location, which would fit to the idea of Bridgeman et al. (1997) that illusory motion, but not location, has direct access to action control. However, it might be premature to exclude location effects on the basis of the present findings. It has been shown that the activation of response codes by corresponding stimuli decays over time (Hommel, 1994), so that effects induced by stimulus location are measurable only about 500–700 msec after stimulus onset. In Experiment 4, the displaced frame and the (absolute and frame-relative) target location were visible much longer than that before the imperative stimulus was presented. Thus, even if the target would have been spatially coded and even if that code would have accessed the corresponding response, the long delay until the actual response would have allowed

any response code activation to decay and, thus, would have eliminated any Simon effect.

One possibility to test this idea is to avoid any preexposure of the frame and the target location, which, however, also requires dropping the motion manipulation. Accordingly, Experiment 5 was designed to test whether a Simon effect to illusory position information can be obtained with static displays consisting of a target that is asymmetrically surrounded by a frame: Frame displacement to the left would facilitate right-hand responses—as the target appears to be positioned on the right—whereas frame displacement to the right would lead to faster left-hand responses. If this could be demonstrated, it would indicate direct access of induced location information to action control.

## Method

**Subjects**. Eight adults were paid to participate in single sessions of about 30 min. They reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment.

**Apparatus and Stimuli**. The stimuli and the apparatus were the same as those in Experiment 2 with the following exceptions. The subjects responded by pressing a left key and a right key. A centrally located target appeared simultaneously with a frame that was displaced either to the left or to the right. The target was either red or green, the response-relevant colors. The frame measured $20° \times 5°$ and was offset by 5° to the left or right of the target. These stimulus parameters were approximately the same as in Bridgeman et al. (1997), so that we expected the position of the target to be misperceived.

**Design**. The subjects worked through 50 experimental blocks. Each block was composed of the four possible combinations of 2 target colors (or response locations) and 2 frame displacements. The mapping of color onto response location was counterbalanced across subjects.

**Procedure**. The procedure was the same as that in Experiment 3 with the following exceptions. After an intertrial interval of 1 sec, frame and target appeared simultaneously and stayed on for no longer than 0.9 sec.

## Results

Trials with response omissions (0.7%) were excluded from analysis. Mean RTs and PEs were computed as a function of response direction and motion direction. An ANOVA on RT revealed a significant main effect of response location [$F(1,7) = 9.13$, $p < .05$], indicating that right responses were faster than left responses (464 vs. 493 msec). The interaction of response location and frame offset was significant [$F(1,8) = 10.75$, $p < .005$]. Left responses were faster when the frame appeared on the right (i.e., the illusory target position was on the left) than when it appeared on the left (484 vs. 503 msec). Conversely, right responses were faster when the frame appeared on the left than when it was on the right (451 vs. 477 msec), amounting to a net correspondence effect of 22 msec. An ANOVA on PEs yielded no significant effects. Inspection of the error rates gave no indication of a speed–accuracy tradeoff. With left responses, more errors were made with left frame displacement than with right displacements (2.4% vs. 2%). The opposite was true with right responses (1.5% vs. 1.7%).

## Discussion

Clearly, the induced position bias yielded a Simon effect. When the illusory target position corresponded to the response location, responses were faster than with noncorrespondence. Thus, both illusory target position and illusory target motion (Experiments 1, 3, and 4) yield Simon-like effects. Presumably, the absence of a Simon effect to the relative target position in Experiment 4 was due to response code decay (Hommel, 1994) that resulted from the relatively long interval between onset of frame and target and response initiation. Thus, we conclude that illusory left–right position and induced motion that result from a surrounding context have access to the motor system and are not exclusively contained in the cognitive map.

## GENERAL DISCUSSION

In the present series of experiments, we explored the potential effects of illusory target motion and position on choice RTs. In Experiments 1, 3, and 4, we found that manual responses were faster when the direction of induced motion and response location or direction corresponded than when they did not. Experiments 2 and 3 ruled out the possibility that attentional shifts accounted for the effects. Experiments 3 and 4 demonstrated that the Simon effect can also be obtained to smoothly induced motion and that the effect persists even when the position of the target relative to the frame is decoupled from the direction of illusory motion. Finally, Experiment 5 showed that a similar effect was obtained with static stimuli that appeared to be displaced to the left or right due to the Roelofs effect (Bridgeman et al., 1997; Roelofs, 1935). Such an outcome does not support the notion of distinct and separate cognitive and motor maps as proposed by Bridgeman et al. (1997)—hence, between different and independent systems mediating perception and action. According to this notion, perceptual illusions should affect only perception, but not action. Since effects of spatial S–R compatibility are widely believed to be related to action control, not to perception, they should not be affected or mediated by induced target motion or illusory target position; yet, the present findings clearly show that they are. Obviously, then, the information delivered to action systems is not necessarily, or not always, more veridical than that flowing to perceptual systems.

We are not the first to show that context effects on stimulus perception can have an impact on response selection and S–R compatibility. For instance, there is accumulating evidence that the way a stimulus is coded as left or right depends on the task and the alternative stimulus locations. Evidence for left–right coding has been observed when stimuli appear to the left or right of body midline (Umiltà & Liotti, 1987), to the left or right of an attended object (Nicoletti & Umiltà, 1989), or in the left or right visual hemifield (Lamberts, Tavernier, & d'Yde-

walle, 1992). This shows that, in spatial coding, a given stimulus the whole range of possible stimulus locations is considered, thus inducing some kind of spatial reference frame that mediates spatial stimulus coding. Interestingly, there is evidence that several such reference frames can be active at the same time, so that multiple spatial codes are available for the same stimulus (Lamberts et al., 1992; Roswarski & Proctor, 1996).

Spatial stimulus coding has also been shown to depend on the task-irrelevant visual context. For instance, Hommel and Lippa (1995) displayed stimuli that were superimposed on the eyes of a human face and had subjects make left–right responses either to the position or to the color of the stimuli. In both cases, left responses were faster to stimuli appearing in the left eye than were responses to stimuli appearing in the right eye, and the opposite was true for right responses, even when the face was tilted by 90°, such that the stimuli appeared above or below fixation. That is, the visual context produced spatial coding of the stimuli in terms of left and right, although the stimuli did not vary in the horizontal dimension. Similarly, Stins and Michaels (1997) asked subjects to push or pull a joystick to stimuli displayed on a texture gradient that provided geometric information about distance. With stimuli that appeared on the "far" side of the gradient, push responses were faster, even though the stimuli appeared on a two-dimensional screen. Again, this indicates that the global context surrounding the stimuli affected the way they were spatially coded.

The present findings are consistent with the already available evidence and extend it in several ways. First of all, they show that dynamic and static, context-induced illusions of the type used by Bridgeman et al. (1981) and Bridgeman et al. (1997) affect response selection in similar ways as the hitherto used static contexts. This is important because it was these kinds of illusion—and their differential effect on perception and action—that provided the empirical basis for the notion of distinct and independent cognitive and motor maps. Moreover, the present study is the first to report a spatial S–R compatibility effect without any real variation of stimulus location. In previous studies on context effects, there were always at least two possible stimulus locations, and the context was used only to induce a particular reference frame used for the coding of these locations. Such manipulations always leave some room for theoretical interpretation. For instance, Stins and Michaels (1997) interpreted their results as showing that subjects automatically pick up objective, actor-related "affordances" in the sense of Gibson (1979)—hence, process the visual information in a more or less veridical way. In the present study, however, it is difficult to see in which way a stationary target would objectively afford a left- or right-hand action. Obviously, both the perceptual and the action systems of our subjects fell prey to an illusionary interpretation of the visual display, even though this effect may very well disappear under more ecological conditions.

However, doubts about the existence of separate cognitive and motor maps even in ecologically valid situations may be raised. For instance, Aglioti, DeSouza, and Goodale (1995) reported that the Ebbinghaus (or Titchener) illusion deceived perceptual judgments, but not grasping responses. The Ebbinghaus illusion is observed when a target object is surrounded by smaller or larger objects. The size of the target object is underestimated with large surrounding objects, whereas it is overestimated with small objects. The dissociation of perceptual and motor performance measures for the Ebbinghaus illusion follows a logic similar to that used by Bridgeman and colleagues. However, more recently, it was found that movement time in the grasping condition was affected by the illusion (van Donkelaar, 1999) and that the illusion had identical effects when perceptual and grasping tasks were appropriately matched (Franz, Gegenfurtner, Bülthoff, & Fahle, 2000). The failure of Franz et al. to replicate the results obtained in the original work by Aglioti et al. could be accounted for by a previously unknown superadditivity of the illusion. Furthermore, *same–different* judgments about the size of objects did not differ in conditions in which size was physically varied relative to a condition in which variations in size were illusory—that is, resulted from the Ponzo illusion (Proctor, Van Zandt, & Watson, 1990; Watson, 1981). Extending these findings from size to time estimates, it has been shown that motor measures of time do not differ for illusory and real motion. Port, Pellizer, and Georgopoulos (1996) demonstrated that interceptive responses to apparent motion of targets did not differ significantly from those to real motion of targets. Taken together, these findings suggest that motor performance is affected by illusory perceptual information even in more natural scenarios.

A further implication of the present findings is that people seem to be rather selective with regard to the visual input processed. Note that there was a compatibility effect with regard to the illusory motion or position of the target, and not to the displacement of the context. Obviously, our subjects did not process the motion/position of the context up to a level that could affect response selection, showing that spatial stimulus information is not translated into corresponding response activation as automatically as some recent S–R compatibility models imply (e.g., De Jong et al., 1994; Kornblum et al., 1990). Instead, context only indirectly affected response selection by modifying the spatial interpretation of the stationary target. This suggests that the "automatic" translation of spatial stimulus codes into response codes is a postattentional (or, perhaps better, attention-contingent) process in the sense that it depends on task-specific attentional control settings (Folk et al., 1992; Folk et al., 1994).

We have pointed out that the observation of interactions between illusory position/motion and manual response selection sheds considerable doubt on the notion of independent cognitive and motor maps fed by different streams of visual information. One possible conclusion from this would be to abandon the idea of two separate pathways altogether and to assume a common representational basis for both perceptual and action-related processes (e.g., Smeets & Brenner, 1995). Provided that only one multipurpose representation of the environment exists, dissociations between different stimulus-related measures may merely reflect differing degrees of sensitivity of these measures—with perceptual reports and automatic response activation in S–R compatibility tasks being more sensitive than pointing responses, such as those performed in Bridgeman et al. (1981) and Bridgeman et al. (1997).

Another alternative is to admit that motor maps may not always represent the environment as veridically as hitherto believed and, thus, may be less "motor" and more "cognitive" than commonly assumed. In fact, it makes much sense to consider that the degree to which motor maps are cognitive strongly depends on the action type. In the studies of Bridgeman and colleagues, the typical response consisted of a temporally unconstrained aiming movement with the dominant hand, an action that is likely to be closed-loop controlled. In contrast, we employed speeded keypress or stylus responses, actions that are likely to be open-loop controlled and ballistic. Obviously, the relative contribution of "cognitive" action-planning processes will be greater with open-loop control than with closed-loop control, and the opposite will be true for contributions from the currently available environmental stimulation. If so, and if the central, more cognitive part of action control is more affected by perceptual illusions than is the peripheral closed-loop part, fast, ballistic manual movements should in fact be more likely to reflect illusions than should slow, environmentally guided pointing movements. Therefore, it may not be so surprising that evidence for the independence of cognitive and motor maps can be found with the latter but not with the former.

At any rate, we conclude from the present observations that the view of distinct and functionally independent cognitive and motor maps needs at least some revision. Whether or not there actually are occasions where functional dissociations between perception and action can be unequivocally demonstrated, it seems clear by now that the radical claim of a complete separation of perceptual and action-related representations and processes cannot be upheld.

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