A Simon Effect With Stationary Moving Stimuli

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To clarify whether motion information per se has a separable influence on action control, the authors investigated whether irrelevant direction of motion of stimuli whose overall position was constant over time would affect manual left–right responses (i.e., reveal a motion-based Simon effect). In Experiments 1 and 2, significant Simon effects were obtained for sine-wave gratings moving in a stationary Gaussian window. In Experiment 3, a direction-based Simon effect with random-dot patterns was replicated, except that the perceived direction of motion was based on the displacement of single elements. Experiments 4 and 5 studied motion-based Simon effects to point-light figures that walked in place—displays requiring high-level analysis of global shape and local motion. Motion-based Simon effects occurred when the displays could be interpreted as an upright human walker, showing that a high-level representation of motion direction mediated the effects. Thus, the present study establishes links between high-level motion perception and action.

The influence of stimulus–response (S-R) relations on reaction times (RTs) is well-documented for static situations. Classical studies by Fitts and Deininger (1954) showed that choice RTs are longer when the spatial arrangement of the response keys corresponds to that of the stimuli to be responded to. For example, when participants are instructed to press a left key in response to a stimulus appearing on the left and the right key in response to a stimulus appearing on the right side, their responses are fast and accurate. Performance drops dramatically when the left response is mapped onto the right stimulus and vice versa. The advantage of more "natural" S-R assignments has been referred to as *stimulus–response compatibility* (SRC).

Similar effects occur when spatial attributes of the stimulus are task irrelevant. For instance, participants may be instructed to respond to a blue stimulus with a left response and to a red stimulus with a right response. Although the imperative stimulus dimension, color, is nonspatial, responses are faster if the irrelevant horizontal stimulus position corresponds to the responses' position: Left responses are faster when the blue stimulus appears on the left than when it appears on the right. The influence of irrelevant spatial stimulus features on performance has been termed the *Simon effect* (Simon, 1969; Simon & Rudell, 1967).

Most researchers agree that the Simon effect is compelling evidence for strong interactions between stimulus-related and response-related codes. The cognitive code for, say, a left stimulus has to interact in some way with the cognitive code representing a left response in order to account for the RT advantage. Coding accounts (e.g., Kornblum, Hasbroucq, & Osman, 1990; Prinz, 1990, 1997; Wallace, 1971) posit that the Simon effect is due to a conflict of two response codes, one generated for the irrelevant stimulus dimension (i.e., location) and the other for the relevant stimulus dimension (e.g., color), that indicates a certain response specified by task instructions. According to dual-route models (Kornblum et al., 1990), the code representing the irrelevant spatial feature automatically activates or primes the corresponding response code, whereas the code representing the relevant color dimension is intentionally translated into the correct response. Thus, advantages in cases of S-R correspondence are attributed to preactivation of motor codes. Approaches that basically assume that processes of perception and action share a common representational domain would argue more radically: Stimuli and responses draw on the same cognitive codes such that RT advantages result when the same cognitive entity that is used to generate the motor response is activated by a corresponding perceptual event (Hommel, Müsseler, Aschersleben, & Prinz, 2001).

Most of the presently available studies on spatial SRC and Simon effects have focused on static situation with fixed stimulus and response positions. Dynamic situations involving changes of position over time have only rarely been examined (cf. Michaels, 1988; Proctor, Van Zandt, Lu, & Weeks, 1993). This is peculiar, because many objects in our daily environment move, and it has long been recognized that the detection and interpretation of object motion is a rich source of information that can be used for a variety of tasks, such as depth perception, object recognition, course control, and collision avoidance (cf. Gibson, 1979). Also, dynamic situations are more likely to occur outside of the laboratory.

Motion Direction Versus Relative Position

Theoretically, moving objects are interesting because they reveal how the cognitive system deals with dynamic situations. There are two principled ways in which a dynamic situation may be represented. First, it may be characterized by the consequence of the movement itself, namely the displacement of the moving object over time. The dynamic aspect would then be represented by the relation between the last seen and the previously occupied positions, most notably the starting position of the object. For instance, an object moving to the left may be characterized by the last seen position being to the left of the position first seen. Second, a dynamic situation may be described by motion vectors that possess both direction and magnitude. These higher-order attributes are independent of positions. For instance, the difference between last seen and first seen position may be calculated and stored to represent the dynamic situation. The important point is that motion vectors can be independent of the positions presented; instead, motion direction is determined and represented. In contrast, a relative position-based representation depends on the positions and their relations.

The present study aims at distinguishing the relative contributions of these two factors for a direction-based Simon effect. Particularly, our emphasis is on contributions of direction-based representations in addition to the (already known) contributions of position-based representations. One problem in addressing this issue is that both contributions are often confounded, and most previous studies dealing with moving objects have failed to disentangle this confound. One of the first studies with dynamic stimuli and dynamic responses was conducted by Michaels (1988). In her study, participants saw a rectangle that appeared to move either toward or away from them and at the same time to their left or their right. Participants were instructed to respond either to the *origin* or to the *destination* of the rectangle's movement by pushing a joystick forward. For instance, a rectangle starting on the left side of the computer screen and moving toward the right had a "left" origin and a "right" destination. When the origin was the relevant stimulus dimension, responses were faster if they spatially corresponded to the origin of the rectangle than if they did not. However, when participants responded to the destination, responses were faster when the stimulus appeared to move toward the side of the responding hand, even when stimulus location did not correspond to response location. Michaels interpreted this motion-based Simon effect in terms of the theory of affordances (Gibson, 1979). That is, the forward movement of the joystick toward the object's destination location may be considered a catching-like response afforded or specified by the (potentially) catchable moving object. Rephrased in the language of coding theories, the ecological account would hold that interactions between stimulus and response codes are action specific. That is, the fit between stimuli and responses (i.e., the affordance relation) would determine whether a compatibility effect was obtained.

Proctor et al. (1993) replicated Michaels's (1988) destination effect with keypresses—that is, with static responses that did not allow for a "catching" of the stimulus. Given the replication, they claimed that direction-based stimulus codes (TO THE LEFT) prompt not only direction-based codes but position-based response codes (ON THE LEFT) as well. This argues against action-specific

S-R relations. A similar destination effect was obtained for static stimuli (arrows), which indicated motion direction but did not prompt catching responses. These results were considered evidence against an interpretation in terms of affordances and in favor of abstract spatial codes that are indifferent to the distinction between directions and positions. Proctor et al. (1993) concluded from their findings that "there is nothing special about motion per se in the destination compatibility effect. Rather, for moving stimuli as for static stimuli the left–right distinction conveyed by the stimulus properties appears to specify relative location only" (p. 89). A similar account was offered by Proctor, Lu, Van Zandt, and Weeks (1994) in a subsequent discussion with Michaels (1993), who had reported a destination compatibility effect for an object that apparently moved on a circular trajectory. The stimuli were designed such that future and past motion of the object were in opposite directions. Because a correspondence effect was obtained to the future direction of object motion, she claimed that the idea of destination compatibility was supported. However, Proctor et al. argued that the future direction of motion was confounded with the relative position of the stimulus. In Michaels' study, an object that moved to the left but was expected to move to the right would also be to the right of targets that were expected to continue moving to the left. In sum, although the Simon effect was observed for dynamic stimuli, it is still unclear whether this was due to a representation that operates on (relative) position codes. The major difficulty is to disentangle relative position and direction of motion.

It is common knowledge that relative coding of target positions explains most of the spatial correspondence effects in static situations. That is, participants may relate the stimulus position to a certain reference object, and this relative location of the target is coded (cf. Hommel, 1993b; Hommel & Lippa, 1995; Kerzel, Hommel, & Bekkering, 2001; Lamberts, Tavernier, & d'Ydewalle, 1992; Proctor & Lu, 1994; Nicoletti & Umiltà, 1989; Umiltà & Liotti, 1987; Umiltà & Nicoletti, 1985). For instance, a target stimulus may be presented to the left of an irrelevant context element, but both stimuli appear on the right half of the screen. Nevertheless, left-hand responses to the target stimulus are facilitated because, relative to the context element, the target stimulus is located on the left. This suggests that the spatial code framed with respect to the target stimulus is determined by the relation between target and context element, implying that the Simon effect is due to the relative left–right coding of stimulus locations. Relative coding has mainly been studied in static situations, but it may easily be applied to dynamic situations as well.

Most previous studies on dynamic SRC have been highly favorable for relative position coding, because in them the starting position of the stimulus was shown for a rather long time. For instance, in Michaels's (1988) and Proctor et al.'s (1993) studies, the stimuli (squares) flashed for 500 ms. Target presentation times at the following positions were much shorter: 240 ms (in Michaels, 1988) and 300 ms (in Proctor et al., 1993). Thus, participants were induced to relate the target position during motion to the starting point. In other words, the long exposure duration may have turned the starting position into a reference point. Therefore, not motion information per se but the current position of the target relative to starting position may have been crucial for direction-based Simon effects. In line with this hypothesis, there was no direction-based

Simon effect in a study by Ehrenstein (1994; Experiment 2, Condition A), in which a small light-dot appeared and immediately moved in a certain direction. Thus, when stimulus- and motion-onset coincided, it was likely that participants did not use the starting position of the target as a reference point for relative position coding.

Further, when direction of target motion was pitted against relative target position, a dominance of relative target position was observed. Nattkemper and Prinz (2001) presented a circle that moved horizontally on-screen. At a random point along the trajectory, a rectangle was superimposed on the circle and remained stationary while the target continued to move (see Figure 1). Thus, the rectangle marked a position previously occupied by the moving stimulus. Simultaneous with the onset of the rectangle, the imperative feature—the color red or blue—was presented. The imperative feature appeared on either the moving circle or the stationary rectangle. Participants were instructed to make a left- or rightward stylus movement in response to the color. When the moving target carried the imperative feature, a direction-based Simon effect occurred—responses were faster when the direction of circle motion corresponded to that of the stylus movement, although motion direction was irrelevant. However, when the stationary rectangle carried the imperative feature, the direction-based Simon effect was reversed. Responses were faster when the direction of circle motion did not correspond to the direction of the stylus movement. This is consistent with the hypothesis that the relative position of the imperative feature determined performance. For instance, when the target moved to the left, and the circle changed color when the stationary rectangle appeared, the imperative feature was left of the rectangle because the circle continued to move to the left. Therefore, left responses were faster. In contrast, when the target moved to the left, and the rectangle changed color, the imperative feature was on the right of the circle because the circle
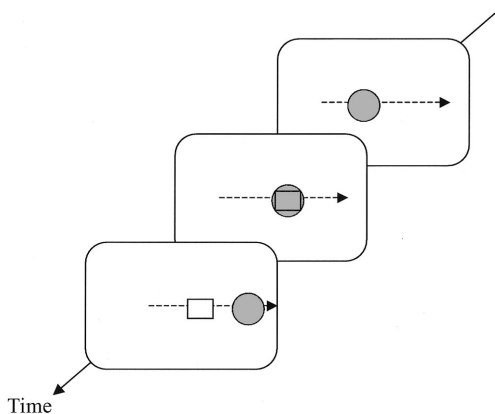
Figure 1. Illustration of an example trial of Nattkemper and Prinz's (2001) study. The trial started with the presentation of a circle moving horizontally to the right at a constant velocity. At a random position along the trajectory, a rectangle was superimposed on the circle. While the rectangle remained stationary at this position, the circle continued to move. At the same time, one of these stimuli turned to a different color (imperative feature). When the imperative feature appeared on the rectangle, responses to the left were faster than responses to the right. The opposite was true when the color cue appeared on the circle.

continued to move to the left. Therefore, right responses were faster. According to this interpretation, relative position coding information fully explains effects that are presumably based on motion direction.

Recently, we presented a large body of evidence in support of this view (Bosbach, Prinz, & Kerzel, 2004): Indeed, it seems to be the case that observers relate the current stimulus position (i.e., at that moment the response is selected) to an earlier stimulus position (e.g., starting position). This implies that S-R compatibility relies to some degree on overlap between the relative position of the current stimulus and that of the upcoming response (cf. Kornblum et al., 1990; Prinz, 1990).

Aim of Present Study

The present study addresses two related questions. First, we ask whether motion information has a separable influence on action control independent of the object's spatial position. To clarify this issue, we investigated whether a Simon effect is obtained when motion information is isolated and relative position coding is rendered highly unlikely. To this end, we chose situations in which motion was shown within an otherwise stationary object that prevented a recoding of motion information in relative position information. Accordingly, these stimuli could not be coded as located ON THE LEFT–RIGHT but only as moving TO THE LEFT–RIGHT. If relative position coding were necessary for the Simon effect to occur, no direction-based Simon effect should be found. However, if motion direction per se were represented and directly affected response selection, a Simon effect should be obtained.

In the first two experiments, a drifting sine-wave grating, which conveyed motion information in the absence of a position shift of the grating itself, was used. Motion in the sine-wave grating was produced by displacing luminance differences (see Figure 2). This type of first-order motion (Cavanagh & Mather, 1989) may be detected at very early stages of visual processing, such as striate cortex (V1; for an overview, see Lu & Sperling, 2002; Nakayama, 1985). In the other three experiments, we presented motion that is invisible to low-level motion detectors in V1. In Experiment 3, we confronted our participants with a random-dot pattern (cf. Newsome, Britten, & Movshon, 1989; Shadlen & Newsome, 2001) consisting of randomly positioned small crosses plotted within a stationary circular aperture. The essential feature of such a display is that displacements of single elements do not specify the overall direction of motion. In Experiments 4 and 5, biological motion was created by rendering a point-light walker (see Figure 3; Johansson, 1973).[1] Although motion processing may be vastly different for drifting sine-wave gratings, random-dot patterns, and point-light walkers, these types of motion have in common the fact that no spatial reference or position shift of the stimulus as a whole is presented. Rather, the stimuli move in place. (Sample stimuli can be viewed on our Webpage: www.allpsych.uni-giessen. de/dk/demo/)

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[1] Note that we do not assume that the perception of biological motion—for instance, in terms of human locomotion—is independent of low-level motion processing (see, e.g., Mather, Radford, & West, 1992), but we do assume that low-level motion processing itself is not sufficient to detect biological movement.
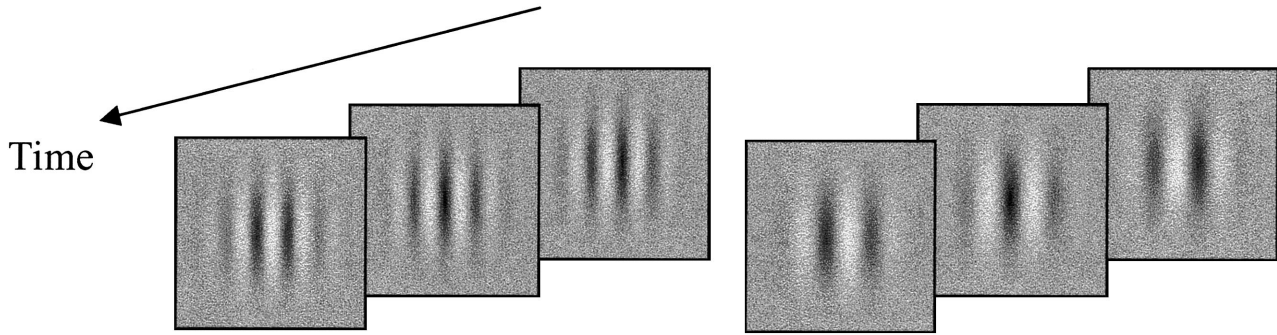
Figure 2. A drifting sine-wave grating with high spatial frequency (narrow stripes) on the left and low spatial frequency (broad stripes) on the right. Over time, the grating appears to drift toward the left. The drifting sine-wave function was multiplied with a stationary Gaussian function (Gabor patch) such that the pattern did not change its overall position while clearly conveying motion information. The spatial frequency (width of the stripes) served as the imperative stimulus dimension in Experiment 1.

The second question pertains to cross talk between direction and position. We used left–right keypresses as responses throughout. These responses are coded as relative positions, such as ON THE LEFT, rather than directions, such as TO THE LEFT. Thus, any correspondence effect between motion stimuli that do not allow for coding of relative position and stationary responses that imply such coding would show that there may be cross talk between direction and position, indicating that response position can be recovered from motion direction.

Experiment 1: Dynamic Versus Static Gabor Patches

Experiment 1 examined whether a direction-based Simon effect can be demonstrated with stimuli conveying reference-free motion detectable in early stages of visual processing. A vertical sine-wave grating was created by modulating the luminance of successive horizontal positions in a sinusoidal manner (see Figure 2). Along the vertical dimension, the luminance values stayed the same. The resulting pattern resembled a vertical black-and-white stripe pattern with smooth transitions between black and white. The spatial frequency of the grating determined the width of the stripes. High spatial frequencies corresponded to narrow stripes, and low ones corresponded to broad stripes. Participants were instructed to respond as quickly and accurately as possible to the spatial frequency of the grating. That is, broad stripes were mapped onto the left key, and narrow stripes were mapped onto the right key, or vice versa. To confine the extent of the grating to a fixed area, the sine-wave function was multiplied with a stationary 2-D Gaussian function. Thus, a circular window of the grating was visible, and transition from sine-wave grating to background was smooth. The horizontal position of the grating was smoothly changed, such that left- or rightward motion resulted. However, the position of the Gaussian window was fixed so that motion was only visible in a well-defined stationary area. The product of a sine-wave grating and a Gaussian function is referred to as a *Gabor patch*.

In the experiment, the Gabor patch appeared on the left or right side of a central fixation point. Peripheral presentation of the patch was preferred because several studies have shown that the percep-

tion of coherent motion is prominent in the periphery (e.g., Lorenceau & Shiffrar, 1992). The Gabor patches were either stationary or dynamic. In the dynamic condition, the sine-wave grating in the Gaussian window drifted to either the left or right. This stimulus gave the impression of motion in a certain direction without changing its position over time or relative to another object. Thus, relative position coding was unlikely. In the stationary condition, sine-wave gratings did not move. In both conditions, the participants' task was to press a left or right key in response to the spatial frequency of the grating.

The design allowed for analysis of two types of correspondence: *Direction-based correspondence* refers to the relation between direction of stimulus motion and response location. *Position-based correspondence* refers to the relation between stimulus position on the screen and response location. Of course, evaluation of direction-based correspondence is restricted to the dynamic condition. Note that both motion direction and relative position were task-irrelevant. We aimed to test whether the irrelevant stimulus dimensions, especially the irrelevant motion information, would affect response selection. Thus, if motion information per se extracted from the stimulus is sufficient to produce a Simon effect, correspondence between motion direction and response location would produce better performance than would noncorrespondence. Similarly, correspondence between stimulus position and response location would entail better performance than noncorrespondence.

Method

Participants. Eighteen students of the Ludwig-Maximilians-University, Munich, Germany, were paid for participating in single sessions of about 50 min. All participants reported having normal or corrected-to-normal vision, normal color vision, and no motor impairments. None of the participants was informed in advance of the purpose of the experiment.

Apparatus and stimuli. Stimulus presentation and data acquisition were controlled by a Matrox Millenium graphics adapter on a Pentium 166 PC, permitting a pixel resolution of 1280 × 1024, and were controlled by custom-written C-programs that made use of the shareware ALLEGRO/ DJGPP game-programming library, run under the DOS-operating system. Stimuli were presented on a 21-in. (53.34-cm) screen. Displays were

updated at a rate of 85 Hz. The average luminance level of the display was 10 cd/m². In the Gabor patch, a sinusoidal grating with a contrast of 100% (i.e., 0–20 cd/m²) was windowed by a 2-D Gaussian envelope with a standard deviation of 1°. The resulting Gabor patch had a radius of about 2° as the luminance approached the background luminance at about 2 standard deviations. In the static condition, a stationary sine-wave grating was shown at a random phase. In the dynamic condition, the grating drifted within the stationary envelope. The spatial frequency of grating was set to 1 or 1.5 cycles per degree, and the temporal frequency was set to 2.8 Hz (resulting velocities being 2.8°/s and 1.87°/s, respectively). The sine-wave grating moved as soon as it appeared in the dynamic condition. Thus, onset of motion and imperative stimulus (i.e., spatial frequency) coincided. The target stimulus was located at the eccentricity of 2.5°, which was defined as the distance between the fixation point and the center of the Gabor patch. Responses were made by pressing a left (Z on an American keyboard) or right (?–/) key of the computer keyboard with the corresponding index finger. Distance between response keys was 17.2 cm.

Design. In the static condition, the sine-wave grating did not move, but in the dynamic condition, the grating drifted. Static and dynamic conditions were blocked, and the order was balanced across participants. Each block in the static condition was composed of the possible combinations of two spatial frequencies (or response locations), two target positions, and two repetitions, randomly intermixed. Each block in the dynamic condition was made up of the possible combinations of two spatial frequencies, two target positions, and two directions of motion. Participants worked through 35 blocks per condition, consisting of 8 trials in each block, preceded by about 20 practice trials. Half of the participants responded to broad stripes (low spatial frequency) by pressing the left response key and to narrow stripes (high spatial frequency) with the right response key, whereas the other half received the reverse stripe width–key mapping.

Procedure. The experiment took place in a dimly lit room. Participants sat at a distance of about 50 cm from the computer screen, with head positioned on an adjustable chin rest. They were instructed to respond as quickly and accurately as possible to the spatial frequency of the target stimulus, irrespective of stimulus motion or position. After an intertrial interval of 700 ms, the next trial started with the presentation of a fixation point 500 ms before the Gabor patch appeared. Participants were instructed to maintain fixation on the central dot. Then the target stimulus appeared, either to the left or right of fixation. Gabor patches were shown for 300 ms.

Responses with RTs longer than 1,000 ms were regarded as missed trials, and responses shorter than 100 ms were regarded as anticipations. These RTs were discarded from analysis. Pressing the wrong key counted as a choice error. If the response was wrong, too early, or too late, auditory and visual feedback was given, and the trial was recorded and repeated at some random position in the remainder of the block. After the first experimental block, participants were given the opportunity to rest.

Results

Anticipations and missed trials (1.9%) were excluded from analysis. Choice errors (4.6%) were analyzed separately. Two kinds of correspondence were defined: position-based and direction-based correspondence. Trials were coded as *position corresponding* when the position of the target spatially corresponded to the response location and *direction corresponding* when the direction of the drifting grating corresponded to the response location. When the position or direction of the target spatially did not correspond to the response location, trials were coded as *position-* or *direction noncorresponding*, respectively. Mean RTs for corresponding and noncorresponding conditions were calculated (see Table 1). To investigate the time course of the correspondence effects, RTs for each condition and participant were rank ordered, divided into quintiles, and averaged. First, a three-way repeated measures analysis of variance (ANOVA; Static vs. Dynamic Condition × Quintile × Position-Based Correspondence) was run to evaluate whether effects of position-based correspondence varied as a function of stimulus motion. Second, a separate three-way analysis (Quintile × Position-Based Correspondence × Direction-Based Correspondence) was run to evaluate effects of direction-based correspondence and possible interactions with position-based correspondence in the dynamic condition (cf. Table 2).

Static versus dynamic condition. The repeated measures ANOVA showed no significant main effect for static versus dynamic condition, $F(1, 17) = 0.02$, $MSE = 3,127$, $p = .898$, but a

Table 1

Mean Reaction Times (RTs, in Milliseconds), Standard Errors (SEs), Percentage of Errors (PEs), and Difference in Mean RTs (ΔRTs) in Experiments 1 and 2 as a Function of Position- or Direction-Based Correspondence

| | Position-based correspondence | | | | | Direction-based correspondence | | | | |
| | Noncorresp. | | Corresp. | | | Noncorresp. | | Corresp. | | |
Condition	RT (*SE*)	PE	RT (*SE*)	PE	ΔRT (*SE*)	RT (*SE*)	PE	RT (*SE*)	PE	ΔRT (*SE*)
					Experiment 1					
Stat./dyn.	493 (10.5)	4.9	487 (11.5)	4.6	6 (3.8)					
Static	494 (11.5)	4.7	487 (12.5)	4.7	7 (3.9)					
Dynamic	492 (10.1)	5.0	487 (11.5)	4.5	6 (3.4)	493 (10.5)	5.0	486 (10.8)	4.5	6 (2.3)
					Experiment 2					
Stat./dyn.	426 (9.2)	4.5	418 (8.5)	4.4	8 (2.7)					
Static	425 (9.4)	4.8	415 (8.8)	5.0	11 (2.6)					
Dynamic	426 (10.2)	4.2	420 (8.8)	3.9	6 (3.3)	425 (9.5)	3.9	421 (9.3)	4.2	4 (2.0)

Note. Means are shown for conditions with a static Gabor patch, a dynamic Gabor patch, and averaged across the static (Stat.) and dynamic (dyn.) conditions. Note that the static condition does not allow for the analysis of direction-based correspondence. Noncorresp. = noncorrespondence; Corresp. = correspondence.

Table 2
Mean Reaction Times (RTs, in Milliseconds), Standard Errors (SEs), Percentage of Errors (PEs), and Difference in Mean RTs (ΔRTs) in Experiments 1 and 2 as a Function of Position- and Direction-Based Correspondence

| | Position-based noncorrespondence | | | | | Position-based correspondence | | | | |
| | Noncorresp. | | Corresp. | | | Noncorresp. | | Corresp. | | |
Experiment	RT (*SE*)	PE	RT (*SE*)	PE	ΔRT (*SE*)	RT (*SE*)	PE	RT (*SE*)	PE	ΔRT (*SE*)
1	494 (10.3)	5.4	490 (10.2)	4.6	4 (3.2)	491 (11.3)	4.5	482 (11.9)	4.4	8 (3.5)
2	427 (10.2)	3.9	424 (10.2)	4.6	3 (2.4)	423 (9.0)	3.8	417 (8.8)	3.9	6 (2.5)

Note. Noncorresp. = (direction-based) noncorrespondence; Corresp. = (direction-based) correspondence.

significant main effect for quintile, $F_{(4, 68)} = 347.56$, $MSE = 1,449$, $p < .001$, indicating that RTs increased over quintiles, from 391 ms in the first to 612 ms in the fifth quintile. There was no significant main effect for position-based correspondence, $F_{(1, 17)} = 2.89$, $MSE = 1,264$, $p = .107$. However, the Quintile × Position-Based Correspondence interaction reached significance, $F_{(4, 68)} = 26.37$, $MSE = 151$, $p < .001$, indicating that the position-based effect decreased with increasing response latencies (cf. Figure 3). The position-based effect was significant in the first two quintiles, $t_{(17)} = 6.10$, $p < .001$ and $t_{(17)} = 3.98$, $p = .001$, but not in the remaining quintiles ($ps > .17$; $ts < -1.43$). Finally, there was a tendency for a significant Static Versus Dynamic Condition × Quintile interaction, $F_{(4, 68)} = 2.30$, $MSE = 104$, $p = .067$. There was no other significant interaction term ($ps > .13$; $Fs < 1.9$).

A two-way repeated measures ANOVA (Static vs. Dynamic Condition × Position-Based Correspondence) on proportion of choice errors did not reveal any main effects or interactions ($ps > .55$; $Fs < 1$).

Dynamic condition. The three-way ANOVA (Quintile × Position-Based Correspondence × Direction-Based Correspondence) showed a significant main effect of quintile, $F_{(4, 68)} = 301.48$, $MSE = 1,600$, $p < .001$, indicating that RTs increased over quintiles, from 393 ms in the first quintile to 610 ms in the fifth. No main effect for position-based correspondence was found, $F_{(1, 17)} = 1.97$, $MSE = 1,410$, $p = .179$, but a significant main effect for direction-based correspondence emerged, $F_{(1, 17)} =$ 7.01, $MSE = 480$, $p = .017$, indicating faster responses in direction-corresponding trials and slower responses in direction-noncorresponding trials (486 vs. 493 ms). Again, the Quintile × Position-Based Correspondence interaction reached significance, $F_{(4, 68)} = 19.57$, $MSE = 209$, $p = .001$, indicating that the position-based effect decreased with increasing response latencies. The position-based effect was significant in the first two quintiles, $t_{(17)} = 5.64$, $p < .001$ and $t_{(17)} = 3.78$, $p = .002$, and a tendency of a significant reversed effect was found in the fifth quintile, $t_{(17)} = -1.89$, $p = .075$, but not in the remaining quintiles ($ps > .35$; $ts < .1$). The Quintile × Direction-Based Correspondence interaction was not significant, $F_{(4, 68)} = 0.76$, $MSE = 117$, $p = .555$. Finally, neither the Position- × Direction-Based Correspondence, $F_{(1, 17)} = 0.92$, $MSE = 532$, $p = .351$, nor the Quintile × Position- × Direction-Based Correspondence interaction, $F_{(4, 68)} = 0.61$, $MSE = 106$, $p = .656$, was significant.

A two-way repeated measures ANOVA (Position-Based Correspondence × Direction-Based Correspondence) on proportion of choice errors revealed no main effects or interactions ($ps > .30$; $Fs < 1$).

Discussion

The main finding of this experiment was that a direction-based Simon effect emerged with a drifting Gabor patch. Responses were faster when the grating drifted in a direction that corresponded to the location of the correct response than when it did not. This result indicates that correspondence effects may occur in the absence of relative position coding. Responses were influenced by the direction of motion conveyed by a drifting grating. This result provides evidence for the view that spatial codes are not exclusively based on (relative) position but that purely motion-based codes, such as TO THE LEFT, do exist. However, the present results also show that response activation may occur between direction-based stimulus codes and position-based response codes. This does not preclude the possibility, however, that the strength of the response activation depends on the similarity between stimulus and response codes. For instance, it is possible that response activation was higher when the response was dynamic so that dimensional overlap (Kornblum et al., 1990) between moving stimulus and response increased. Indeed, an objection may be raised about the size of the motion-based Simon effect: Typically, a position-based Simon effect is on the order of about 20 ms; the Simon effect observed here was, however, rather small (7 ms). Nevertheless, the
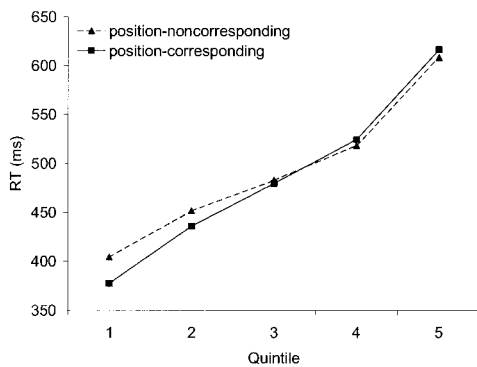

Figure 3. Mean reaction times (RTs) as a function of quintile and position-based correspondence in Experiment 1.

effect was in the range of previously reported correspondence effects (e.g., Hommel & Lippa, 1995; cf. Hommel, 1996). It should also be noted that we minimized error variance by using a within-subject design and collecting a rather large number of repetitions per condition. (The individual means for direction-corresponding and noncorresponding conditions in this experiment were based on 140 trials each.)

Surprisingly, in neither the condition with a stationary grating nor that with a moving grating was a significant position-based Simon effect obtained. That is, no matter whether the Gabor patch was presented to the left or to the right of fixation, (irrelevant) position information did not influence response selection. One reason may be the choice of the imperative stimulus dimension. Participants had to discriminate the different spatial frequencies of the Gabor patch. This task may be more difficult than, for instance, color discrimination. Hommel (1993a, 1994) has shown that the more difficult the processing of the relevant stimulus feature is, the more likely it is that the automatically induced response activation decays before the response is selected. If this is so, automatic response activation from stimulus position may have decayed when our participants had to discriminate spatial frequencies. Support for the decay hypothesis comes from the analysis of the RT distribution. The quintile analysis showed that the position-based correspondence effect in both experimental conditions decreased with increasing RTs.

Experiment 2: Dynamic Versus Static Colored Gabor Patch

In Experiment 1, no position-based Simon effect was found. The absence of this effect may be attributed to the rather difficult distinction of the imperative stimulus dimension and the resulting response code decay (cf. Hommel, 1993a, 1994). That is, because it was difficult and more time consuming to recognize the response-relevant stimulus features, the response activation induced by the stimulus position may have decayed and not been able to affect response selection. To test this idea, we replicated Experiment 1 with a color cue as the response-relevant stimulus feature. Participants were asked to respond to the color of the Gabor patch rather than to its spatial frequency, a task which may be easier, more quickly performed, and is likely to prevent response code decay. We also used a somewhat larger eccentricity of the stimulus to ensure peripheral motion processing (cf. Lorenceau & Shiffrar, 1992). Further, we varied the time of the stimulus color onset asynchrony (SCOA) relative to motion onset, first in order to investigate the potential time course of the correspondence and second to ensure unpredictability of the imperative stimulus onset.

Method

Participants. Sixteen students of the Ludwig-Maximilians-University, fulfilling the same criteria as in Experiment 1, were paid for participation. None of them had participated in Experiment 1.

Apparatus and stimuli. This experiment was a replication of Experiment 1, with the following exceptions. Spatial frequency of the pattern was held constant at 1 cycle per degree. After 150, 300, or 450 ms, the pattern changed its color from gray to red or blue while maintaining luminance. The colored Gabor patch was visible for 300 ms. Again, there were two conditions. In the static condition, the sine-wave grating did not move. In the dynamic condition, the sine-wave grating drifted within the stationary envelope. The target stimulus was located at an eccentricity of 4°. The eccentricity was defined as the distance between the fixation point and the center of the Gabor patch.

Design. Each block was composed of the possible combinations of two target colors (or response locations), two positions of the target, two directions of motion (or repetitions in the static condition), and three SCOAs. Participants worked through 10 blocks per condition, consisting of 24 trials in each block, preceded by about 20 practice trials.

Procedure. The same procedure was used as in Experiment 1.

Results

Anticipations and missed trials (1.3%) were excluded from analysis. Choice errors (4.4%) were analyzed separately. Mean RTs were computed as a function of static versus dynamic condition, quintile, SCOA, and position-based and direction-based (if applicable) correspondence (see Table 1).

Static versus dynamic condition. The repeated measures ANOVA did not reveal a main effect for static versus dynamic condition, $F(1, 15) = 0.24$, $MSE = 7,358$, $p = .634$, but did reveal a significant main effect for quintile, $F(4, 60) = 236.51$, $MSE = 4,360$, $p < .001$, indicating that RTs increased over quintiles, from 337 ms in the first quintile to 530 ms in the fifth quintile. Additionally, a significant main effect for SCOA was found, $F(2, 30) = 68.56$, $MSE = 2,239$, $p < .001$, indicating that RTs decreased with increasing SCOAs, from 446 at 150 ms SCOA to 404 at 450 ms SCOA. Contrary to Experiment 1, a significant position-based Simon effect occurred, $F(1, 15) = 8.97$, $MSE = 1,706$, $p = .009$, indicating that responses that spatially corresponded to the position of the target were faster than responses that did not (418 vs. 426 ms). The position-based effect did not vary with quintile, $F(4, 60) = 0.88$, $MSE = 310$, $p = .480$. Additionally, there was a significant Static Versus Dynamic Condition × Position-Based Correspondence interaction, $F(1, 15) = 4.14$, $MSE = 367$, $p = .060$, so that the position-based effect was more pronounced in the static than in the dynamic condition (10 vs. 5 ms). Finally, a tendency for a significant Quintile × SCOA interaction was found, $F(8, 120) = 1.78$, $MSE = 319$, $p = .088$. No other significant interaction term emerged ($ps > .24$; $Fs < 1.5$).

A second three-way ANOVA (Static vs. Dynamic Condition × SCOA × Position-Based Correspondence) on proportions correct did not reveal any significant effects ($ps > .19$; $Fs < 1.9$).

Dynamic condition. The four-way ANOVA revealed a significant main effect for quintile, $F(4, 60) = 198.22$, $MSE = 5,437$, $p < .001$, indicating that RTs increased with increasing quintile, from 336 ms in the first to 533 ms in the fifth quintile. Additionally, a significant main effect for SCOA occurred, $F(2, 30) = 60.70$, $MSE = 2,958$, $p < .001$, indicating that RTs decreased with increasing SCOA, from 449 at 150 ms to 404 at 450 ms. Although a significant main effect for position-based correspondence was not confirmed, $F(1, 15) = 2.79$, $MSE = 2,571$, $p = .115$, a significant main effect for direction-based correspondence occurred, $F(1, 15) = 4.63$, $MSE = 986$, $p = .048$. Responses were faster when the direction of motion corresponded to response position and slower when the direction of motion did not correspond to response position (421 vs. 425 ms). The Position- × Direction-Based Correspondence interaction failed to reach significance, $F(1, 15) = 1.22$, $MSE = 434$, $p = .287$ (cf. Table 2), and,

finally, neither position-based correspondence nor direction-based correspondence was a function of quintile, $F(1, 60) = 0.71$, $MSE = 668$, $p = .587$, and $F(1, 60) = 0.70$, $MSE = 679$, $p = .596$, respectively. No other interaction term was significant ($ps > .18$; $Fs < 1.5$).

A second three-way ANOVA (SCOA × Position-Based Correspondence × Direction-Based Correspondence) on error rates did not reveal any significant effects ($ps > .10$; $Fs < 1.1$).

Between-experiments (Experiments 1 and 2) comparison. To investigate whether the absence of the position-based Simon effect in Experiment 1 was due to response-code decay, we compared the mean RTs of both experiments. An independent-samples t test showed significantly shorter mean RTs in Experiment 2 than in Experiment 1 (422 vs. 490 ms), $t(32) = 4.81$, $p < .001$.

Discussion

A direction-based Simon effect occurred when a drifting sine-wave grating was presented either on the left or right side of fixation. This replicates the finding of the first experiment and confirms the hypothesis that task-irrelevant motion information can affect response selection. As in Experiment 1, this direction-based correspondence effect was independent of position-based correspondence: No matter whether the target stimulus position corresponded to the response location, the directional information conveyed by the drifting grating was extracted and coded independently of its position relative to the screen or body midline.

The overall RTs to color in the present experiment were notably shorter than those to spatial frequency in Experiment 1. Therefore, the hypothesis of response-code decay (Hommel, 1993, 1994) may explain the absence of a position-based Simon effect in Experiment 1. In Experiment 2, there was no time course of the position-based Simon effect. It is possibly that there is a certain temporal limit beyond which response code occurs, and this limit may have been passed in Experiment 1 only. Further, the two experiments suggest that the response-code decay varied for position- and motion-based codes because RTs did not differ between the static and dynamic conditions in Experiment 1, yet decay was found for

position-based but not for direction-based correspondence. Overall, RTs were shorter the later the color changed within a trial. This finding came as no surprise, because a color change occurred in every trial and so response expectancy and preparation increased over the course of a trial (cf. Bertelson, 1967).

Experiment 3: Dynamic Random-Dot Display

A possible objection to our conclusion that the motion-based Simon effects in Experiments 1 and 2 were due to direction coding and not to relative position coding comes from a microanalysis of the stimulus (cf. Figure 4): If participants had considered a single element in the display, they might have coded the position of a single stripe relative to its starting position. This was unlikely, because the stripes were not continuously visible but went out of sight when they reached the edge of the Gaussian window. However, the possibility remains that participants focused on single elements in the stimulus.

To render such a strategy impossible, in Experiment 3, we used a random-dot pattern in which displacements of single elements did not specify the overall direction of motion (cf. Newsome et al., 1989; Shadlen & Newsome, 2001). Our participants saw two circular "clouds" of small crosses, simultaneously presented above and below a central fixation mark (cf. Figure 5). Each cross in the stimulus was shown for one refresh cycle, and after about 60 ms it reappeared within a 1-degree^2 area. The displacement between two successive presentations of a cross was random, with the following constraint: The probability of a single cross being displaced toward the left or right was 3%, 12%, or 21%. This probability is referred to as *coherence of element displacement*. Note that the displacement of a single element never fully specified the motion signal inherent in the global signal. Rather, the global impression of motion was based on the summation of local displacements. As the coherence of element displacement increases, it becomes easier to discriminate the direction of the motion signal.

In each trial, the elements changed their shape after some time to indicate which response was to be emitted. Either the vertical or the horizontal lines disappeared such that each element consisted

Real View **Schematic View**
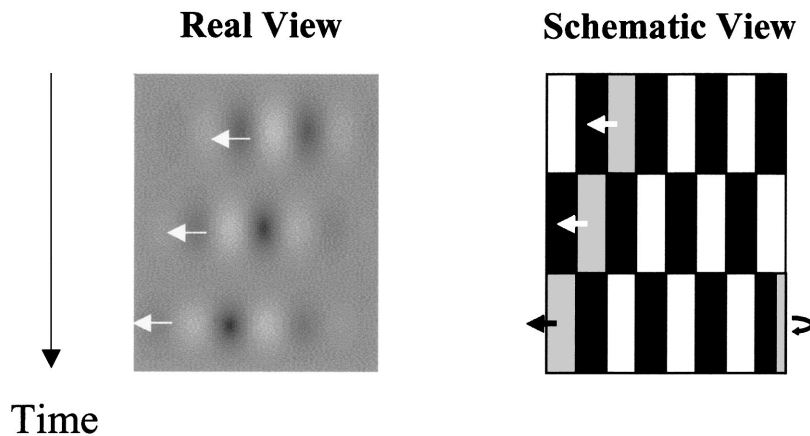
Time

Figure 4. The position of each single stripe within the Gabor patch changes over time (in this example, position displacement is to the left). The patch as a whole remained stationary. Participants may have coded the relative displacement of single elements in the stimulus.
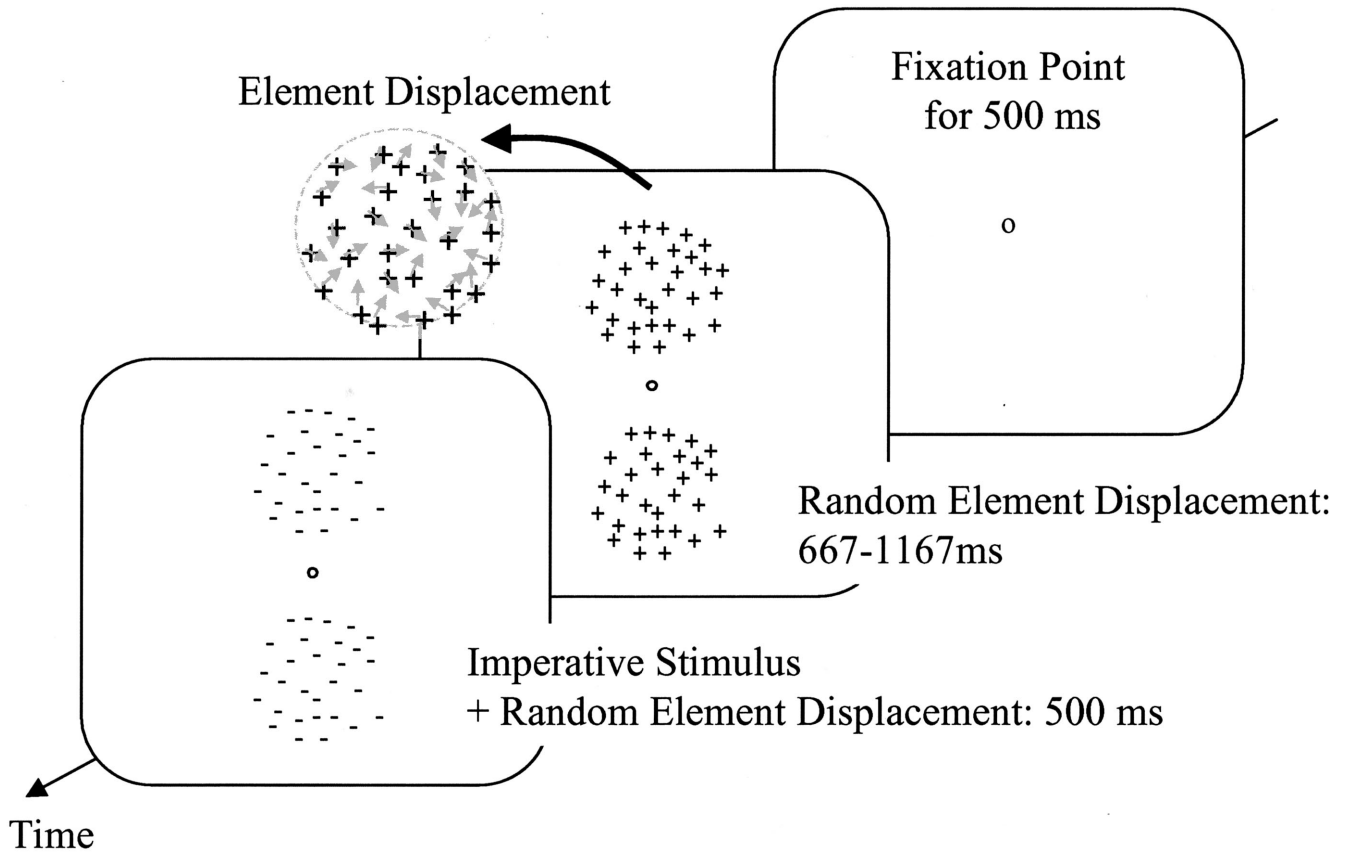
Figure 5. Illustration of the trial structure in Experiment 3. Each trial started with the presentation of a central fixation point 500 ms before stimulus onset. Then, two "clouds" of crosses appeared simultaneously above and below central fixation. Each element was displaced every 67 ms, but there was no synchrony between the displacements across elements. The probability of a single cross being displaced toward the left or right was 3%, 12%, or 21%. This probability was the coherence of element motion. Finally, 500 ms before display termination, the elements changed their shape (imperative stimulus) to indicate which response should be given.

of only a horizontal or a vertical line (cf. Figure 5). In one part of the experiment, participants were asked to press a certain key indicated by the orientation of the elements (vertical vs. horizontal lines) as quickly and accurately as possible, and motion information was task-irrelevant (Simon task). In another part of the experiment, participants were asked to judge the direction of motion in the visual stimulus. The motion-direction judgment task was necessary to investigate whether a motion-based correspondence effect would be observed even though participants were unable to discriminate motion direction.

Method

Participants. Sixteen students of the Ludwig-Maximilians-University, fulfilling the same criteria as in Experiment 1, were paid for participation. None of them had participated in Experiment 1 or 2.

Apparatus and stimuli. Stimulus presentation and data acquisition were controlled by the same apparatus as in Experiment 1, except that the pixel resolution and refresh rate were reduced to 1024 × 768 and 60 Hz, respectively. The visual display contained two circular areas, each with a diameter of 6°, and in each area stimulus elements (0.21° × 0.21° crosses

or 0.21° vertical–horizontal lines) were randomly positioned at a density of 1 element per degree[2]. The two fields were presented simultaneously above and below a central fixation mark.[2] The distance between the fixation point and the center of the field was 9°. Each element within the field was displayed for one frame and replotted at a random position four frames later (i.e., the stimulus onset asynchrony was 67 ms). The probability that a single element was displaced toward the left (or right) was 3%, 12%, or 21%, and the displacement was consistent with a velocity of 7°/s. The initial onsets of the stimulus elements were random so that the displacements were asynchronous. Display duration varied randomly between 1,167 and 1,667 ms. Initially, crosses were shown, and 500 ms before offset the crosses turned into horizontal or vertical lines. The nature of element displacement did not change after the stimulus elements had changed shape. In the Simon task, participants were asked to respond to the orientation of the elements by pressing one of two keys (cf. Experiment 1). In the motion-direction judgment task, participants were asked to report the perceived direction of motion by pressing one of two keys.

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[2] We presented two fields to cover a relative large stimulus area and to prevent eye movements.

Design. Participants performed the unspeeded motion-direction judgment task and the speeded two-choice reaction task blockwise. Task order was balanced across participants. Each block was composed of the possible combinations of two target lines (or response locations), two directions of motion, and three coherence levels of the motion signal. Participants worked through 12 blocks per task, consisting of 24 trials in each block, preceded by 2 practice blocks of each task per 48 trials. In the two-choice reaction task, half of the participants responded to vertical lines by pressing the left response key and to horizontal lines with the right key, whereas the other half received the opposite line orientation–key mapping.

Procedure. The procedure was the same as in Experiment 1, with the following exceptions. A trial started with a centrally presented fixation point. After 500 ms, the two target stimuli were shown simultaneously above and below fixation. Participants were instructed to maintain fixation on the central dot. Then, either the horizontal or the vertical line of the small crosses disappeared. In the two-choice reaction task, participants pressed the left or right key on the keyboard, irrespective of perceived stimulus motion (cf. Experiment 1). They were instructed to respond as quickly and accurately as possible. In the motion-direction judgment task, participants had to report the perceived motion direction by pressing the left key for perceived leftward motion and the right key for perceived rightward movement. There was no time limit for the response in the latter task.

Results

The motion-direction judgment task and the two-choice reaction time tasks were analyzed separately.

Motion-direction judgments. We calculated the percentage of correct directional judgments as a function of coherence and conducted a repeated measures analysis with coherence level as the within-subject variable. Additionally, one-sample t tests with 50% as test value were carried out for each level. The ANOVA showed a significant main effect of coherence, $F(2, 30) = 50.99$, $MSE = 40$, $p < .001$, indicating that performance improved with coherence. Mean percentages of correct responses were 56.9%, 71.4%, and 79.0% for coherence levels of 3%, 12%, and 21%, respectively. For all coherence levels, the mean percentage of correct answers was significantly different from chance. The least significant t value, $t(15) = 5.02$, $p < .001$, was observed with 3% coherence.

Choice reaction. Anticipations and missed trials (1.5%) were excluded from analysis. Choice errors (5.5%) were analyzed separately. Mean RTs were computed as a function of direction-based correspondence and coherence of the motion signal (cf. Table 3).

To investigate the time course of the potential correspondence effect, an RT-distribution analysis was run (cf. Experiment 1). A three-way ANOVA (Quartile × Coherence × Direction-Based Correspondence) revealed a significant main effect for quartile, $F(3, 45) = 487.38$, $MSE = 1,674$, $p < .001$, indicating that RTs increased over quartiles, from 432 ms in the first to 650 ms in the fourth quartile.[3] In addition, we found a significant main effect for coherence, $F(2, 30) = 7.50$, $MSE = 377$, $p = .002$, indicating that RTs increased with increasing coherence of the motion signal, from 528 ms at 3% coherence to 537 ms at 21% coherence. However, a significant Quartile × Coherence interaction occurred, $F(6, 90) = 2.58$, $MSE = 185$, $p = .024$, indicating that the increase in RTs with increasing coherence of the motion signal grew larger over quartiles. The difference between the strongest and the shortest coherence level was 3 ms in the first quartile and increased to

Table 3

Mean Reaction Times (RTs, in Milliseconds), Standard Errors (SEs), Percentage of Errors (PEs), and Difference in Mean RTs (ΔRTs) in Experiment 3 as a Function of Coherence Level and Direction-Based Correspondence

	Noncorresp.		Corresp.		
Coherence	RT (*SE*)	PE	RT (*SE*)	PE	ΔRT (*SE*)
3%	526 (14.3)	6.5	529 (14.0)	6.1	−3 (2.9)
12%	535 (14.5)	4.4	527 (14.2)	4.4	8 (3.7)
21%	542 (14.3)	7.7	532 (13.3)	4.4	9 (3.4)

Note. Noncorresp. = (direction-based) noncorrespondence; Corresp. = (direction-based) correspondence.

20 ms in the fourth quartile. Furthermore, a significant main effect for direction-based correspondence was found, $F(1, 15) = 5.09$, $MSE = 401$, $p = .039$, indicating that responses were faster when they spatially corresponded to the direction of the random-dot motion than when they did not (530 vs. 534 ms). However, the direction-based effect was modulated by the coherence of the motion signal, $F(2, 30) = 4.15$, $MSE = 334$, $p = .026$. A significant direction-based correspondence effect was only observed with 21% coherence of the motion signal: RTs were shorter when the direction of the motion signal corresponded to response location than when they did not (533 vs. 542 ms), $t(15) = 2.76$, $p = .015$. This effect was not quite significant with 12% coherence (527 vs. 535 ms), $t(15) = 2.04$, $p = .060$, but far from significant with 3% coherence (529 vs. 526 ms), $t(15) = -0.99$, $p = .340$. There was no other significant interaction term ($ps > .47$; $Fs < 1$).

A second two-way ANOVA (Coherence × Direction-Based Correspondence) on proportions correct revealed a tendency for a significant main effect of coherence, $F(2, 30) = 2.90$, $MSE = 1.003E-03$, $p = .073$. No other significant effects were found ($ps > .12$; $Fs < 2.7$; cf. Table 3).

Discussion

A direction-based Simon effect was obtained when a dynamic stimulus that did not change its overall position was presented above and below central fixation. As in the previous experiments, this means that responses were faster when the perceived motion direction corresponded to the position of the response. Single displacement of elements did not reliably specify the direction of motion of the global stimulus. Rather, perception of motion direction required that displacement of single elements be integrated over space (and time). This provides further evidence for our hypothesis that motion information per se, and not relative position information, activates corresponding motor responses. Further, the stimulus provided directional information at different coherence levels, and the probability that participants correctly discriminated the directional information increased with increasing coherence.

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[3] We divided RTs for each condition and each participant into quartiles, not quintiles as in the other experiments, to ensure that the total number of RTs resulting from the total number of repetitions in this experiment (i.e., 288 repetitions) was divisible without remainder.

The same was true for the direction-based correspondence effect. When participants performed only slightly above chance detection level (with 3% coherence), there was not even the slightest indication of a direction-based Simon effect. However, when detection performance was around the detection threshold of 75% correct, the effect was (marginally) significant. This finding lends support to the notion that the perceived motion information only affects response-selection processes when observers are "aware" of this information. Although previous interpretations of the Simon effect have emphasized the automaticity of response activation by spatial information, the present findings show that this automatic process is not independent of voluntary or attentional control. In other words, intentionally guided or controlled processes set the stage for automatic processes (cf. Hommel, 2000).
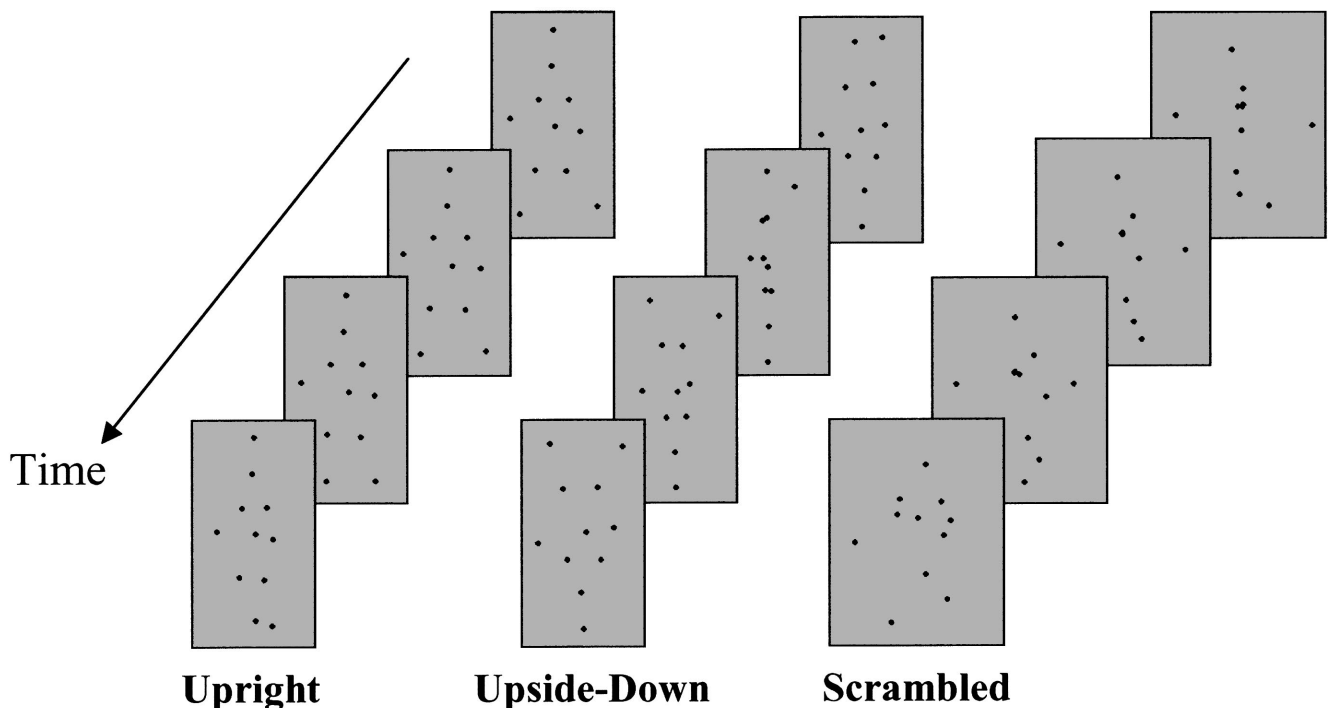
Experiment 4: Point-Light Walker

The first three experiments showed that participants extracted directional information from stationary moving stimuli even if motion information was task-irrelevant. Processing of this directional information resulted in more efficient responses in cases in which the direction corresponded to the response location. The underlying representational basis of this effect cannot be a relative position code, because the stimuli did not vary in position. Rather, the participant had to encode motion information per se. In the stimuli used in our previous experiments, there was a perfect

(Experiments 1 and 2) or minimal (Experiment 3) correlation between the displacement of single elements and the overall direction of motion. In the present experiment, we investigated biological motion in which the (relative) displacement of single elements has no relation to the overall direction of motion.

A familiar example of biological motion is Johansson's (1973) point-light walker display (see Figure 6). In Johansson's original work, lights attached to the major joints and head of an actor were visible in an otherwise dark area, with only the lights visible. The body was hidden in darkness. Actors were filmed while performing various acts, such as walking. Naive observers had an immediate experience of a walking person, although only 11–13 dots were visible. The information conveyed in the moving-dot pattern was sufficient to reconstruct and identify the depicted biological object motion.

Johansson (1973, 1976) proposed that the preliminary level of visual analysis is local and proceeds automatically: The author assumed that moving elements of the stimulus field are continuously interrelated, whereby simultaneous movements in the same direction are combined to form a perceptual unit. That is, the relative motion between elements is used to calculate the motion of the overall pattern. From this theoretical perspective, it is not surprising that most of the subsequent work favored an explanation in terms of low-level or bottom-up processing. Meanwhile, there is growing evidence that higher level mechanisms and representa-

Figure 6. Illustration of Johansson's (1973) point-light walker display: 11 dots constituted a human figure seen upright (left and right panels) or upside down (central panel). The coherent walkers (left and central panels) were used in Experiment 4. In Experiment 5, a few dots of the walker's figure were spatially transposed to destroy the coherent spatial relations among the dots (right panel; cf. Bertenthal & Pinto, 1994). The scrambling procedure eliminated possible directional cues available in the global shape of the (static) figure.

tions are also involved in the perception of biological motion (e.g., Bertenthal & Pinto, 1994; Dittrich, 1993; Thornton, Rensink, & Shiffrar, 2002). For instance, some studies (Bertenthal, 1993; Bertenthal & Pinto, 1994; Sumi, 1984) have revealed that observers were able to recognize an upright point-light walker, but identification rates fell markedly or identification took significantly longer when an upside-down point light walker was presented. That is, although the same biological motion was shown— but in a different orientation—participants could not (directly) extract directional information. Additional evidence for the importance of high-level processing of biological motion was provided by neurophysiological studies: McLeod, Dittrich, Driver, Perrett, and Zihl (1996) showed that a motion-blind patient who had a lesion in the medial temporal cortex was not able to cope with several motion tasks, such as detecting the movement or coding the velocity of single moving dots, but was able to identify instead the action of a biological motion display. Oram and Perrett (1996) reported that neurons of the superior temporal polysensory area of macaque monkeys responded selectively to body movements of a point-light walker. Thus, extrastriate cortex may be involved in the processing of biological motion, whereas processes in V1 are insufficient and may not even be necessary.

In Experiments 4 and 5, we used a point-light walker, which conveys—as in the prior experiments—motion information without a change of relative position over time.[4] Again, motion information was irrelevant because participants were instructed to respond to the color of the walker. In most conditions, we did not inform participants about the nature of the displays but described them as dynamic dot patterns (*dot pattern instruction*).

The point-light walker was either presented upright in action (walking in place), upside down in action, or upright and static. The walker's color could turn from black to red or blue after a variable delay. Participants were instructed to respond to the color of the walker as quickly and accurately as possible. Blue and red were mapped onto left and right response keys. Our hypothesis was that a Simon effect would only emerge with upright walkers, because naive participants would only be able to recognize the walker in this position. Thus, only the upright walker condition would be able to convey direction information and activate response codes. In the condition with an upside-down walker, there was certainly the same biological motion and the same relative motion between elements, but it would be difficult, if not impossible, to recognize the dynamic pattern as a moving person (cf. Bertenthal, 1993; Bertenthal & Pinto, 1994). Therefore, the participants would not be able to extract the direction of the walker motion, and no response activation would occur. To test whether participants would be able to do so if they knew that a walker was presented in the upside-down condition, we informed them about the nature of the display in one condition (*walker instruction*) but not in the dot pattern instruction condition. Finally, we presented a static walker to see whether cues inherent in the shape of the walker would be sufficient to convey directional information.

Method

Participants.   Forty students (10 per condition) of the Ludwig-Maximilians-University, fulfilling the same criteria as in Experiment 1, were paid for participation in a single session of about 30 min. None of them had participated in Experiments 1–3.

Apparatus and stimuli.   Stimulus presentation and data acquisition were controlled by the same apparatus as in the earlier experiments. As a target stimulus, a point-light walker (Johansson, 1973) was used, 3.6° in width (left-to-right hand point along the *x*-axis at the most extended point of the step cycle), 7.2° in height (head point to ankle points along the *y*-axis). The biological motion configuration was generated by modifying Cutting's (1978) classical point-light walker algorithm. The set of 11 dots simulated a walker seen in profile, with lights on the head, near shoulder, both elbows, both wrists, near hip, both knees, and both ankles (see Figure 3). The dots were always visible and did not disappear when they would be occluded by the walker's body. The walker did not move across the screen but walked in place, with either a left- or rightward gait. The walker's starting phase was selected randomly on each trial. The maximum stride width of a walker was about 3.84°. The dots themselves had a diameter of 0.18°. The walker's stride cycle took about 941 ms and consisted of 40 different postures. Each posture was shown for 24 ms.

Four conditions were run: In the *upright* condition, an upright walker in action was presented, and participants were told that they would see a dynamic dot pattern. In the *upside-down* condition, the same walker was presented upside down, and participants were told that they would see a dynamic dot pattern (dot pattern instruction), whereas in another upside-down condition, participants were instructed that the dynamic dots constituted a walker (walker instruction). Finally, in the *static* condition, a static upright walker was shown, and participants were told that they would see a static dot pattern. In each trial of the static condition, a static image of a walker was selected randomly out of a step cycle of 40 single pictures. In each condition, the walker was centrally presented on the screen and after 150, 300, or 450 ms it turned to red or blue. After the color change, the walker stayed on-screen for another 300 ms.

Design.   Participants in each of the four conditions (upright, upside down–dot-pattern instruction, upside down–walker instruction, static) worked through 15 experimental blocks consisting of 24 trials in each block, preceded by about 20 practice trials. Each block was composed of the possible combinations of two target colors (or response locations), two motion directions, and three SCOAs, randomly intermixed.

Procedure.   The procedure was the same as in Experiment 1, except that participants were told that they would see a dynamic dot pattern, a static dot pattern, or a point-light walker upside down. A trial began with a centrally presented fixation point for 300 ms, and then the target stimulus appeared centrally. After 150, 300, or 450 ms, the walker turned red or blue, and participants pressed the left or right key as quickly and as accurately as possible (cf. Experiment 1).

Results

Anticipations and missed trials (1.2%) were excluded from analysis. Choice errors (5.7%) were analyzed separately. A repeated measures ANOVA was conducted with walker condition as the between-subjects variable and quintile, SCOA, and direction-based correspondence as the within-subject variables. To define direction-based correspondence, trials in which motion direction corresponded to response location were defined as direction cor-

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[4] Note that the relative motion of lights attached to the wrists and ankles may specify walker motion to the left; however, neither the wrist nor the ankle is consistently displaced to the left or right with respect to the other because of the cyclical nature of the motion. In contrast, the relative displacement of, say, a single spot of light traveling to the left consistently indicates the direction of overall motion. Thus, even though relative motion of elements in a point-light walker specifies the direction of locomotion when integrated across time and space, the instantaneous relative positions of single elements do not specify the direction of locomotion.

responding and those that did not were defined as direction non-corresponding. For each walker condition, mean RTs for corresponding and noncorresponding trials were calculated (cf. Table 4).

An ANOVA on RT revealed a significant main effect of quintile, $F(4, 144) = 120.86$, $MSE = 1,424$, $p < .001$, indicating that RTs increased over quintiles, from 317 ms in the first quintile to 509 ms in the fifth. Additionally, a significant main effect of SCOA, $F(2, 72) = 23.69$, $MSE = 222$, $p < .001$, indicated that RT decreased with increasing SCOA, from 417 ms at 150 ms to 385 ms at 450 ms. The Quintile $\times$ SCOA interaction reached significance, $F(8, 288) = 413.10$, $MSE = 1,424$, $p < .001$, indicating that the decrease of RTs with increasing SCOA became smaller with quintiles. The RT difference between shortest and longest SCOA decreased from 38 ms in the first to 33 ms in the fifth quintile. The main effect of direction-based correspondence was significant, $F(1, 36) = 6.78$, $MSE = 623$, $p = .013$. When the direction of walker motion corresponded to response location, RTs were shorter than they were when the walker appeared to walk in the opposite direction (396 vs. 399 ms). However, the direction-based correspondence effect was modulated by walker condition, $F(3, 36) = 3.18$, $p = .036$ (cf. Table 4). To further analyze this interaction effect, we ran t tests for each walker condition to evaluate whether the direction-based Simon effect was significantly different from zero: The direction-based correspondence effect reached significance in the upright-walker condition, $t(9) = 3.16$, $p = .012$, but was significant in neither the upside-down walker–dot pattern instruction, $t(9) = -0.53$, $p = .610$, nor the upside-down walker–walker instruction, $t(9) = 0.79$, $p = .450$, or static walker condition, $t(9) = 1.46$, $p = .180$. No other significant interaction effect was found ($ps > .19$; $Fs < 1.5$).

Finally, we conducted an independent samples t test to compare the walker conditions with respect to the correspondence effect (difference between mean RTs in direction-noncorresponding and direction-corresponding trials). We found a significant difference between the upright condition and the upside-down walker–dot pattern instruction condition, $t(18) = 2.74$, $p = .013$, and also between the upright condition and upside-down walker–walker instruction condition, $t(18) = 2.33$, $p = .032$. That is, in both cases, the correspondence effect was larger with an upright walker than with an upside-down walker. There was no significant difference between any other condition ($ps > .17$; $ts < -1.40$).

A second ANOVA with walker condition as a between-subjects variable and SCOA and direction-based correspondence as within-subject variables on error rates revealed a significant Walker Condition $\times$ Direction-Based Correspondence interaction, $F(3, 36) = 3.29$, $p = .031$ (cf. Table 4). The difference on error rates between direction noncorrespondence and correspondence was significant in the upright walker condition, $t(9) = 3.61$, $p = .006$, but it was significant in neither the upside-down walker–dot pattern instruction, $t(9) = -0.32$, $p = .760$, nor the upside-down walker–walker instruction, $t(9) = -0.98$, $p = .350$, or the static walker condition, $t(9) = -0.40$, $p = .700$. No other main or interaction effects were significant ($ps > .10$; $Fs < 2.4$).

Discussion

Biological motion information that could be easily recognized as an upright human walker produced a reliable Simon effect for motion direction. Shorter RTs and fewer errors were obtained in conditions in which the walker seemed to walk in a direction that corresponded to the response location, whereas longer RTs and more errors occurred when the walker seemed to walk in a direction that did not correspond to the response location. A direction-based Simon effect was absent when an upside-down or a static point-light walker was shown. This shows that although the same biological motion was displayed, a change of the orientation of the global form of the walker (upside down) prevented the extraction of directional information. Thus, the encoding of local motion signals is affected by the context in which they are presented. In other words, the recognition of the shape of an upright human was necessary for the extraction of response-relevant directional information.

Also these results support the conclusion from the previous experiments that the direction-based Simon effect is based on the coding of motion direction per se. Thus, coding of the movement itself—that is, the extracted directional information—is a sufficient condition for a direction-based Simon effect to occur. Relative position codes are not necessary.

One problem with Experiment 4 is that the difference between an upright moving walker and an upright stationary walker failed to reach significance. Although direction-based correspondence was not significant with a static upright walker, there was no difference between the Simon effects in the upright static and upright moving conditions. Thus, it may be the case that it was not motion information per se that caused the correspondence effect but static directional features of the walker. Such an effect would be similar to the correspondence effect for arrows reported by

Table 4

Mean Reaction Times (RTs, in Milliseconds), Standard Errors (SEs), Percentage of Errors (PEs), and Difference in Mean RTs (ΔRTs) in Experiment 4 as a Function of Experimental Condition and Direction-Based Correspondence

	Noncorresp.		Corresp.		
Experimental condition	RT (SE)	PE	RT (SE)	PE	ΔRT (SE)
Upright walker	415 (9.0)	6.1	405 (10.6)	3.2	11 (3.3)
Upside-down walker (dot instruction)	393 (12.6)	6.0	394 (13.3)	6.3	−2 (3.0)
Upside-down walker (walker instruction)	391 (14.9)	6.2	389 (16.1)	7.3	2 (2.1)
Static upright walker	399 (15.5)	5.4	394 (15.4)	5.8	5 (3.1)

Note. Noncorresp. = (direction-based) noncorrespondence; Corresp. = (direction-based) correspondence.

Proctor et al. (1993) or Wang and Proctor (1996). In other words, the shape of the walker may have been perceived as pointing toward the left or right, even if no motion was added. To test whether biological motion of the walker was sufficient to convey response-relevant directional information, we conducted a control experiment using a scrambled walker.

Experiment 5: Scrambled Walker

As in the previous experiment, a point-light walker served as a target stimulus, and we asked participants to respond to the walker's color and to ignore its walking direction. This experiment differed from Experiment 4 mainly in that a few of the dots constituting the walker were spatially transposed (see Figure 6). This scrambling procedure aimed at eliminating possible directional cues available in the global shape of the walker. Thus, the static walker display should be hard to interpret when it is stationary, but be readily interpreted as a person walking in a particular direction when in motion. In other words, only motion would enable the observer to organize the dot pattern into a coherent perception of human locomotion, this certainly depending on the nature and extent of the scrambling.

Method

Participants. Sixteen students of the Ludwig-Maximilians-University, fulfilling the same criteria as in Experiment 1, were paid for participation. None of them had participated in Experiments 1–4.

Apparatus and stimuli. This experiment was a replication of Experiment 4, except that the walker was scrambled such that some points of the figure (head, shoulder, hip, wrist, knee, and ankle) were transposed along the x- or y-axis (cf. Bertenthal & Pinto, 1994): The head was transposed 3.4° down along the y-axis from its origin, the shoulder 0.3° up along the y-axis, the hip 2.7° to the right along the x-axis, the left wrist 3.4° to the right along the x-axis, the right knee 2.7° up along the y-axis, and the left ankle 0.7° up along the y-axis.

Design. The design was the same as in Experiment 4, with the following exceptions. The walker was either static or dynamic. Static and dynamic walker presentation was blocked, each block consisting of 240 trials. Block order was counterbalanced across participants.

Procedure. The same procedure as in Experiment 4 was applied.

Results

Anticipations and missed trials (0.8%) were excluded from the analysis. Choice errors (4.5%) were analyzed separately. Mean RTs were computed as a function of static versus dynamic walker condition, quintile, SCOA, and direction-based correspondence. Results are summarized in Table 5.

The four-way ANOVA revealed a significant main effect for quintile, $F(4, 60) = 140.02$, $MSE = 7,638$, $p < .001$, indicating that RTs increased over quintiles, from 317 ms in the first to 513 ms in the fifth quintile. Also, a significant main effect for SCOA occurred, $F(2, 30) = 58.95$, $MSE = 2,010$, $p < .001$, indicating that RTs decreased with increasing SCOAs from 419 ms with 150 ms SCOA to 382 ms with 450 ms SCOA. Additionally, there was a main effect of direction-based correspondence, $F(1, 15) = 12.05$, $MSE = 720$, $p = .003$, which was modulated by whether the walker was moving or not, $F(1, 15) = 4.71$, $MSE = 959$, $p = .046$. A statistically reliable effect of direction-based correspondence

Table 5

Mean Reaction Times (RTs, in Milliseconds), Standard Errors (SEs), Percentage of Errors (PEs), and Difference in Mean RTs (ΔRTs) in Experiment 5 as a Function of Dynamic Versus Static Scrambled Walker and Direction-Based Correspondence

Scrambled walker	Noncorresp.		Corresp.		
	RT (*SE*)	PE	RT (*SE*)	PE	ΔRT (*SE*)
Dynamic	408 (13.2)	4.9	397 (13.8)	4.1	10 (3.3)
Static	393 (10.9)	4.6	392 (10.7)	4.8	2 (1.7)

Note. Noncorresp. = (direction-based) noncorrespondence; Corresp. = (direction-based) correspondence.

was only observed when a dynamic scrambled walker was presented: RTs were shorter when the motion direction of the walker corresponded to the location of the response than when it did not (397 vs. 408 ms), $t(15) = 3.12$, $p < .008$. However, this was not the case if the walker was stationary (392 vs. 393 ms), $t(15) = 0.99$, $p = .340$. The Quintile × Direction-Based Correspondence interaction reached significance, $F(4, 60) = 3.46$, $MSE = 384$, $p = .013$, indicating that the correspondence effect increased over quintiles, from 1 ms in the first to 15 ms in the fifth quintile. A significant Static Versus Dynamic Walker × Quintile × Direction-Based Correspondence interaction, however, occurred, $F(4, 60) = 4.16$, $MSE = 261$, $p = .005$, indicating that the increase of the direction-based correspondence effect over quintiles was more pronounced in the dynamic walker condition (from 2 ms in the first to 28 ms in the fifth quintile) than in the static walker condition (from 0 ms in the first to 2 ms in the fifth quintile). Finally, there was a tendency for a significant Static Versus Dynamic Walker × SCOA interaction, $F(2, 30) = 2.61$, $MSE = 600$, $p = .090$. No other effects approached significance ($ps > .11$; $Fs < 1.7$).

A second three-way ANOVA (Dynamic vs. Static Walker × SCOA × Direction-Based Correspondence) on error rates revealed a significant Static Versus Dynamic Walker × SCOA × Direction-Based Correspondence interaction, $F(2, 30) = 3.37$, $MSE = 7.076E-04$, $p = .048$, indicating that in the dynamic walker condition, the direction-based correspondence effect on error rates (difference in percentage of errors between noncorresponding and corresponding trials) was 0.6%, −0.6%, and 2.2% at 150, 300, and 450 ms SOA, respectively, and in the static walker condition 0%, 0.9%, and −1.3%. No other significant effects were found ($ps > .15$; $Fs < 2.1$).

Discussion

Only when the scrambled walker was set in motion did the direction of the walker have an effect on response latency. When the walker was static, no direction-based correspondence effect was observed. This supports the hypothesis that motion-based directional information underlies the correspondence effect, not static, form-based directional cues. In other words, most participants could not make sense of the static dot pattern as a human figure seen in profile and facing to the left or right. Therefore, they

did not generate a direction-specific code or internal representation that would then influence response selection.

General Discussion

In the present series of experiments, we investigated whether Simon-type effects would arise in response to stimuli that carried motion signals (in the absence of relative position codes). Research on spatial SRC has focused on effects of static stimuli on manual responses. So far, only a few studies have described Simon effects based on motion perception. However, a closer look at the experimental protocols for these studies reveals that the presumed motion-based effects may also be explained in terms of relative position coding. Notably, in a standard dynamic configuration, in which a stimulus travels on a predictable trajectory, relative position and motion information may be effective in parallel. In this situation, there is no way to deconfound their contributions. In the present study, we made an attempt to separate the two possible sources by using stationary moving stimuli. Our results show that motion direction itself can influence the selection of "stationary" responses (keypresses).

We ran five experiments in which we used moving stimuli without a well-defined starting or endpoint of motion. In the first two experiments, we presented motion information predominantly accessible to low-level motion detectors at early stages of visual processing—namely, drifting sine-wave gratings. Motion direction was always irrelevant for the task. Rather, responses were specified by the spatial frequency or color of the stimulus. Experiments 1 and 2 demonstrated that responses were faster when the direction of the drifting grating and the response location corresponded than when they did not.

In Experiment 3, we replicated a direction-based Simon effect with random-dot patterns, which excluded the possibility that the perceived direction of motion was based on single displacements of pattern elements. The Simon effect was only reliable when the probability of a correct perceptual decision about the motion direction was relatively high.

Finally, we explored which level of motion processing was involved in the motion-based Simon effect. To determine which processing stage was necessary for the effect, we used stimuli in which coherent motion could only be detected at high levels of motion processing. To this end, we used Johansson's (1973) point-light walker in different orientations. As in Experiments 1–3, the stimulus carrying the motion information did not change its overall position over time. Also, the local motion of individual dots did not indicate the overall direction in which the walker was moving, because each of the dots was moving back and forth like a pendulum. Only an interpretation of the global configuration of the dots in terms of a walking human would yield the walker's direction of motion. A direction-based Simon effect was only observed when a dynamic upright walker was presented. The effect was absent when the walker was shown upside down (even if observers were told what they would see) or upright but static (Experiments 4 and 5). Our experiments rule out the hypothesis that static features of the walker explain the direction-based Simon effect. In sum, Experiments 4 and 5 show that a high-level representation of motion direction, which probably relies on recovery of structure-from-motion, is crucial for the correspondence effect to occur.

Cross Talk Between Direction and Position

How can we account for the cross talk between direction and position, indicating that motion direction itself can influence the selection of stationary responses at fixed positions? We discuss two such accounts, abstract overlap and implicit position coding. The first possibility is to posit dimensional overlap at the level of more abstract features—at which level perceptual events and motor events are equivalent (Hommel et al., 2001; Kornblum et al., 1990; Prinz, 1990, 1997). Clearly, in our experiments, there could be no overlap between stimuli and responses on low-level dimensions like direction or position. However, stimuli and responses did share the binary feature SIDE (LEFT vs. RIGHT) such that there could be overlap with respect to a more abstract, high-level dimension. With this perspective, the present findings may be taken to show that even semantic similarity, or equivalence, between motion to the left or right and a left or right response position may produce effects of S-R correspondence. In other words, motion direction and response position may be represented as abstract LEFT or RIGHT codes that interact at the level of response selection. This is in line with Kornblum and Lee's (1995) suggestion that "SRC is the direct consequence of the degree to which the stimulus and the response sets of a stimulus–response ensemble are perceptually, conceptually, or structurally similar" (p. 855). In a similar vein, Proctor, Wang, and Vu (2002) concluded that conceptual and not perceptual similarity between stimuli and responses is responsible for SRC effects. Nevertheless, future work will have to clarify whether response activation due to directional information is larger if the response itself was also specified by motion direction such that dimensional overlap between the moving stimuli and responses increased.

The second possibility is to posit implicit position coding. This view maintains that even with stationary moving stimuli observers may be capable of recovering position-from-direction, though perhaps in a way different from regular motion stimuli. Notably, there are two ways to recover position information from motion information—an obvious one and a less obvious one. The obvious way is to rely on backward information, that is, to relate current stimulus position (i.e., at that moment the response is selected) to an earlier position (e.g., starting position). As outlined in the introductory section, there is evidence in support of this view for correspondence effects with regular motion stimuli. It implies that S-R compatibility relies on overlap between relative positions of the current stimuli and relative positions of responses. Still, there is a second, less obvious source of information inherent in motion stimuli from which position information can be recovered: forward information. As is known from classical observations on event perception (Heider & Simmel, 1944; Michotte, 1946/1963), representations of dynamic events do not only carry information about past and present states but about future states as well. For instance, a dot traveling across the screen is perceived as having started at Position A, now reaching Position B, and traveling onwards toward Position C. If this is so, it raises the idea of a correspondence effect based on the similarity between the (anticipated) upcoming

position of the stimulus and the position of the to-be-selected response.

Because of the directedness of their inherent motion, the stimuli used in the present study could be perceived as directed toward a certain region in space. Accordingly, stationary moving stimuli may specify spatial regions for upcoming stimulus positions, and it may be for this reason that the direction of pure motion signals prompts keypresses on the side corresponding to the target region of that motion. Such compatibility effects based on forward information should certainly be weaker than effects based on backward information, because forward information specifies positions of upcoming relative to present events (and, hence, relies on anticipation), whereas backward information specifies positions of present relative to preceding events (and, hence, relies on perception). Obviously, the notion of recovering position from forward information is closely related to Michaels's (1988) concept of destination compatibility. Further, it may be applied to Wang and Proctor's (1996) finding that a static arrow pointing in a certain direction speeds up responses that correspond to the pointing direction of the arrow. In a similar vein, Zorzi, Mapelli, Rusconi, and Umiltà (2003) and Ansorge (2003) have recently shown that responses in the direction of a gaze were faster than responses in the opposite direction. These findings, too, may be explained by an interaction between the target region indicated by the arrow head or gaze and the location of the to-be-selected response.

Motion and Action

The present study establishes previously neglected links between motion perception and action. More precisely, it shows that motion has a separable influence on action control, independent of the object's position in space. Even though motion processing has been well investigated, only a few studies have looked at the links between motion perception and action (a notable exception is oculomotor research; for an overview, see Krauzlis & Stone, 1999). So far, there has been no direct evidence that this kind of motion information is directly linked to motor processes (except for oculomotor processes), although such a link would be highly plausible from an evolutionary perspective. For an animal to survive, it may be of vital importance for it to quickly select an appropriate response given a certain direction of object motion. For instance, the movement of flying prey has to be responded to by movements that follow the prey's movements. If the animal tries to escape to the left, it would make sense to prime responses to this side that would allow for fast catching responses (see also Michaels, 1988). In a way, detecting and responding to object motion may be more important than identifying the exact position and identity of the object. Therefore, motion information may be particularly salient. Thus, the potential evolutionary significance of motion signals makes it very likely that direct links exist between perceptual motion processing and motor processes. However, the present data do not support the hypothesis that S-R relations are action specific ("affordances"). A stimulus moving TO THE RIGHT would be most adequately responded to by a movement TO THE RIGHT. However, we observed that responses ON THE RIGHT were activated.

In sum, we have shown that referential coding (i.e., the relation between present and previous stimulus positions)—even though it may be able to explain most of the previously reported Simon effects in dynamic situations—cannot account for the Simon effects based on pure motion information reported here. The present study is the first to provide unambiguous evidence for a close functional relationship between motion perception and action selection.

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