

# Allocation of attention to biological motion: Local motion dominates global shape

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Directional information can be retrieved from a point-light walker (PLW) in two different ways: either from recovering the global shape of the articulated body or from signals in the local motion of individual dots. Here, we introduce a voluntary eye movement task to assess how the direction of a centrally presented, task-irrelevant PLW affects the onset latency and accuracy of saccades to peripheral targets. We then use this paradigm to design experiments to study which aspects of biological motion—the global form mediated by the motion of the walker or the local movements of critical features—drive the observed attentional effects. Putting the two cues into conflict, we show that saccade latency and accuracy were affected by the local motion of the dots representing the walker's feet—but only if they retain their familiar, predictable location within the display.

Keywords: biological motion, eye movements, attention

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## Introduction

Directional information contained in social cues such as gaze (Friesen & Kingstone, 1998), head (Driver et al., 1999), and body orientation (Lawson, Clifford, & Calder, 2009) is an important clue for determining other people's intentions (Nummenmaa & Calder, 2009). Our visual system can extract directional information even from the degraded human body movement depicted in a stationary point-light walker (PLW) display (Johansson, 1973; Troje, 2002). In the absence of explicit global translational movement, directional information from such displays can still be obtained in two ways: either from the overall, motion-mediated shape of the figure or by means of the local motion of individual dots.

With no explicit depiction of the articulations (e.g., by drawing lines between the joints), motion becomes crucial in mediating the articulated structure (Aggarwal, Cai, Liao, & Sabata, 1998). The articulated structure then provides information about the walker's orientation in space, but this directionality is not really contained in the motion but rather in the motion-mediated shape. In addition, and entirely independent of the directional

information contained in the global shape of a walker, we can derive information about walking direction from the local motion of individual dots (Troje & Westhoff, 2006). This was demonstrated by the fact that observers could retrieve information about a walker's facing direction even from fully scrambled point-light displays. The orientation of the local trajectories does play a role, though. Turning a scrambled point-light walker upside down disrupts the ability to derive directionality. This latter phenomenon was then used to show that most of the local information about facing direction was contained in the motion of the feet (Troje & Westhoff, 2006). Subsequent work has shown that the visual invariants that convey direction from local motion are linked to implicit knowledge about the dynamics of the extremities under conditions of gravity (Chang & Troje, 2009).

The local invariants that convey directionality may serve other purposes as well. Since they are independent of the overall shape of the animal and therefore unspecific with respect to its particular nature, it was suggested that they feed a mechanism that serves the fast, pre-attentional detection of articulated, legged animals in the visual environment. The fact that the visual periphery responds to these invariants

seems to corroborate this idea (Thompson, Hansen, Hess, & Troje, 2007). Another prediction would be that the same cues that convey direction in scrambled biological motion would also have attentional effects. Some evidence for this is in fact provided by Wang, Zhang, He, and Jiang (2010). Moreover, the directional information derived from scrambled motion of PLWs can affect ocular-motor responses. Orban de Xivry, Coppe, Lefevre, and Missal (2010) found a significant positive correlation between the velocity of smooth pursuit and the correct performance on directional judgment for scrambled PLWs.

Social cues effectively control the focus of attention. For example, in a series of eye movement studies, it was shown that another person's gaze direction can affect not only automatic saccades (e.g., Deaner & Platt, 2003) but also the latency of volitional gaze shifts (e.g., Crostella, Carducci, & Aglioti, 2009; Kuhn & Benson, 2007; Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002)—even though the direction of gaze of the centrally presented face was entirely irrelevant for the task the subjects were instructed to do. Participants' saccade latencies were faster when the gaze direction of a centrally presented face corresponded with the target location than when the gaze direction was incongruent with the target location (Kuhn & Benson, 2007). Moreover, participants made more errors on incongruent than on congruent trials.

So far, three behavioral studies have been conducted to address how the direction of a point-light walker (PLW) affects behavioral responses. By adopting a central cueing paradigm, Shi, Weng, He, and Jiang (2010) demonstrated that the walking direction of an upright coherent PLW induced a reflexive shift of observers' spatial attention but not when the walker was shown upside down.

Using a Simon effect task paradigm, Bosbach, Prinz, and Kerzel (2004) observed a stimulus-response incompatibility effect in both reaction time and accuracy for both coherent and scrambled PLWs. Although the participants were instructed only to attend to the color of the dots representing the walker, the reaction time was prolonged and accuracy was decreased when the direction of the PLW was incompatible with the side of the button the participant was cued to press.

Bosbach et al.'s (2004) finding that even scrambled point-light walkers induce a Simon effect seems to contradict data obtained by means of a flanker task paradigm (Thornton & Vuong, 2004). In their study, the authors showed that only the global shape of the PLW appeared to affect reaction time: the direction of PLWs presented in the periphery interfered with direction judgments for a central target PLW but not when the peripheral PLWs were scrambled. The result provided evidence that coherent PLWs can be processed incidentally but not scrambled ones.

In the current study, we use a similar paradigm to investigate whether and how the two sources of directionality contained in point-light walkers affect saccade latency and response accuracy. We used point-light displays depicting a walker in profile view and therefore

containing either rightward or leftward facing cues, along with control stimuli depicting frontal view walkers. The nature of the centrally presented walkers was entirely irrelevant for the task the observers were asked to do. The only task-relevant feature of the point-light displays was a switch in color (either from white to red or from white to green) occurring after a variable interval following stimulus onset. On either side of the PLW was a stationary target square, and the walker's color signaled to the observer the side of the target to which they had to make a subsequent saccade. The facing direction of a centrally presented point-light display was either congruent, neutral, or incongruent with respect to the target location in Experiments 1 and 2. In Experiment 3, two conflicting cues were used, one of which was congruent and the other was incongruent with the target location. We measured onset latencies and accuracies of the saccades made to the color-cued target.

In Experiment 1, we directly compared the effect of global motion-mediated shape and local point-light motion of the walker by using either coherent or scrambled point-light displays. In scrambled point-light displays, local motion is kept intact, but the single-dot trajectories are randomly displaced within a restricted area of the display, entirely disrupting the shape of the figure. As discussed above, there is ample evidence that the feet of the walker play a distinct role in determining direction from local motion (Chang & Troje, 2009; Troje & Westhoff, 2006). Normal scrambling disrupts the walker's shape, which is intended. However, additionally, it also introduces uncertainty about the location of the feet. In order to avoid this confound, we introduced in Experiment 2 a new stimulus: we randomly displaced all dots within the area occupied by the walker, except for the dots representing the feet. The feet thus appeared always in the same location while the overall articulated structure of the walker was still entirely disrupted. To further explore the respective roles of global form and local motion, we set the two cues into conflict in Experiment 3 by introducing a backward walking PLW stimulus. While the motion-mediated shape faces in one direction, the local motion of the feet and all other dots is reversed and thus points in the other direction.

## Experiment 1

Experiment 1 was designed to measure the effect that the global shape and local motion of a PLW had on a voluntary eye movement task.

### Methods

#### Participants

Sixteen observers (age range 17–30 years, mean = 19.0 years, 5 males) participated in Experiment 1. All of

them had normal or corrected-to-normal vision and received course credit for their participation. Informed consent was obtained from all participants.

### Stimuli

The stimuli were derived from point-light sequences of a walking human. The human walker, computed as the average walker from motion-captured data of 50 men and 50 women (Troje, 2002, 2008), was depicted by a set of 11 markers (13 markers for the frontal view) representing the motions of the head, one shoulder, one hip (two shoulders and two hips for the frontal view), two elbows, two wrists, two knees, and two ankles. The translating component of the walk was removed such that the human displayed stationary walking. All walkers were presented in either profile (i.e., facing rightward or leftward) or frontal view and were shown with a gait frequency of 0.93 Hz. For each presentation, the starting position of the walker within the gait cycle was selected randomly. The stimuli were generated using MATLAB (Mathworks, Natick, MA) with extensions from the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997) and were displayed on a 17-inch CRT color monitor (Samsung SynchMaster 735DF),  $1024 \times 768$  pixels spatial resolution, and 75-Hz frame rate. All stimuli appeared as white dots on a black background and the full point-light figures subtended visual angles of  $2.1^\circ \times 4.6^\circ$ .

### Procedure and design

Participants were seated at a viewing distance of 48 cm to a CRT computer screen. They were instructed to ignore the motion of the PLW stimulus and focus their attention on the change of color of the point lights and to saccade their eye as quickly as possible when they detected the change of the color. The colored cue remained visible

until the participants' eye gaze reached the target. For each trial, either 200 or 500 ms after the onset of the point-light motion (stimulus color onset asynchrony: SCOA), the color of the point lights changed from white to either green or red (Figure 1). Half of the participants were instructed to move their eyes to the right when the point lights turned red and to the left when they turned green; for the other half of the participants, the color assignments were reversed. Congruency was defined as follows: congruent trials were those where the saccade target location and the PLW direction as indicated by the global shape were the same; incongruent trials were conditions in which the target location and the PLW direction were opposite to each other; in neutral trials, the walker was facing toward the participant.

Eye movements were recorded with an EyeLink II eye tracker (SR Research, Mississauga, Ontario, Canada) combined with the EyeLink Toolbox (Cornelissen, Peters, & Palmer, 2002) running under MATLAB. The sampling rate of the eye tracker was 500 Hz. The calibration procedure guaranteed a spatial accuracy of at least  $0.5^\circ$ . Before the experiment, participants sat in the chair and put their chin on the chin rest. At the beginning of each session, the participants' eye positions were calibrated. Each trial began with a drift correction. The participant had to focus his or her gaze at a circle presented at the center of the screen. When the participant's eye was fixated on the circle, the circle was replaced with a fixation cross ( $1^\circ \times 1^\circ$ ) that appeared on the screen for 500 ms and was then followed by the point-light display and the saccade targets. The point-light walker was presented at the center of the screen and two white squares ( $0.43^\circ \times 0.43^\circ$ ) were presented at  $8.0^\circ$  of eccentricity in the left and right visual fields. After participants moved their eyes to the squares, the trial was terminated, and the participant was required to fixate again the circle that appeared in the screen.

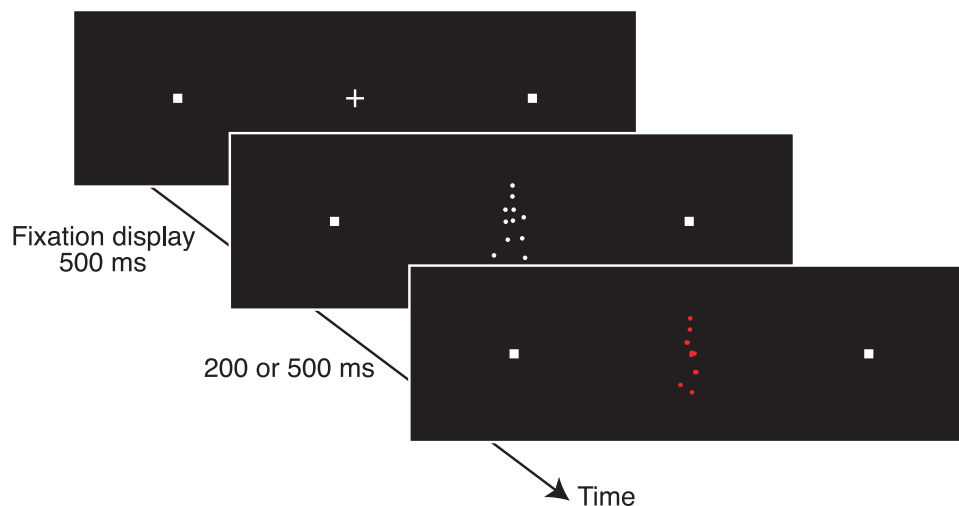


Figure 1. Schematic representation of presentation sequence. After a 500-ms fixation, a white point-light walker was presented for 200 or 500 ms, then the color of the point lights were changed to either green or red.

Participants were tested in two separate blocks, each associated with one type of the walker (coherent or scrambled). One block consisted of five sessions. In each session, each of the directions of the PLWs (left, right, or frontal), the direction of the saccade to the target (left or right), and the two stimulus color onset asynchronies (SCOAs: 200 or 500 ms) were equally probable and were presented in a random sequence. Each one of the 12 possible combinations was repeated 7 times, for a total of 84 trials per session. Thus, 420 trials were performed in one block. Before beginning each experimental block, each subject completed 24 practice trials, which were not included in the analysis. The order of the two experimental blocks was counterbalanced across subjects.

### Data analysis

Data were analyzed offline using custom-developed software. We analyzed subjects' accuracy and latencies by focusing on the first horizontal saccade that followed the instruction cue. The first saccade was detected automatically using a velocity criterion of 30°/s. Saccadic latency was determined as the time difference between the onset of the color change and the start of the saccade. Trials with saccadic latencies below 80 ms were discarded on the basis that these saccades may have been anticipatory and result in chance performance (Bannerman, Milders, de Gelder, & Sahraie, 2009; Kalesnykas & Hallett, 1987). Following common practice (Bannerman et al., 2009; Kuhn & Benson, 2007), latencies exceeding more than 3 standard deviations above the mean were also discarded. With our current experimental settings, we did not find any anticipatory smooth eye movement. We analyzed subjects' directional accuracy by focusing on the first horizontal saccade (velocity criterion > 30°/s) that followed the change of the color and had an amplitude larger than 1°.

For the statistical analysis, three-way ANOVAs were performed both for accuracy and for saccadic latency with coherency (coherent or scrambled), congruency (congruent, incongruent, and neutral), and SCOA (200 and 500 ms) as within-subject variables. Post hoc multiple comparisons were based on Tukey's HSD.

## Results and discussion

For the saccade latencies (Figure 2A), we found that facing direction of the coherent PLW had a significant effect on overt attention at 200-ms SCOA condition. In the statistical analysis, we found significant main effects of SCOA [ $F(1, 15) = 109.2, p < 0.01, \eta_p^2 = 0.88$ ] and congruency [ $F(2, 30) = 22.4, p < 0.01, \eta_p^2 = 0.60$ ], but no effect of coherency [ $F(1, 15) = 0.9, p = 0.36, \eta_p^2 = 0.06$ ]. In addition, there were significant two-way interactions of

coherency  $\times$  congruency [ $F(2, 30) = 3.7, p < 0.05, \eta_p^2 = 0.20$ ] and SCOA  $\times$  congruency [ $F(2, 30) = 5.2, p < 0.05, \eta_p^2 = 0.26$ ]. Moreover, there was a significant three-way interaction of coherency  $\times$  SCOA  $\times$  congruency [ $F(2, 30) = 6.2, p < 0.01, \eta_p^2 = 0.29$ ]. As is clear from Figure 2A, and confirmed by the subsequent analysis, this three-way interaction was due to different patterns of responding to the target at the two SCOAs (200 and 500 ms) for both stimuli. For the coherent PLW, a two-way interaction of SCOA  $\times$  congruency was statistically significant [ $F(2, 30) = 10.7, p < 0.01, \eta_p^2 = 0.41$ ], indicating that the latencies in the incongruent trials were longer than those in the congruent ( $p < 0.01$ ) and neutral trials ( $p < 0.05$ ) when the SCOA was 200 ms. On the other hand, for the scrambled PLW, significant main effects of SCOA and congruency were observed [SCOA:  $F(1, 15) = 170.1, p < 0.01, \eta_p^2 = 0.91$ ; congruency:  $F(2, 30) = 18.4, p < 0.01, \eta_p^2 = 0.55$ ], but no interaction between them. This suggests that the latencies in the 500-ms SCOA trials were shorter than those in the 200-ms SCOA trials, and the latencies for the congruent and incongruent trials were longer than those for the neutral trials. For the 200-ms SCOA, there was a significant two-way, coherency  $\times$  congruency interaction [ $F(2, 30) = 8.1, p < 0.01, \eta_p^2 = 0.35$ ]. This interaction was due to the fact that the latencies in the incongruent trials were significantly longer than the latencies in the congruent ( $p < 0.01$ ) and neutral trials ( $p < 0.05$ ) for the coherent PLW trials. However, the latencies in both congruent and incongruent trials were significantly longer than latencies in the neutral trials for the scrambled PLW trials ( $p < 0.01$ ). For the 500-ms SCOA, there was a significant main effect of congruency [ $F(2, 30) = 16.2, p < 0.01, \eta_p^2 = 0.52$ ] indicating that the latencies in both congruent and incongruent trials were significantly longer than those in the neutral trials irrespective of the coherency of the stimulus.

Mean accuracy levels (percentage of correct responses) for Experiment 1 are displayed in Figure 2B. There were main effects of SCOA [ $F(1, 15) = 25.0, p < 0.01, \eta_p^2 = 0.63$ ] and congruency [ $F(2, 30) = 4.7, p < 0.05, \eta_p^2 = 0.24$ ]. Accuracies in the 200-ms SCOA condition were higher than in the 500-ms SCOA condition. Comparing the differences in accuracy to the differences in saccade latencies, the effects of SCOA might be due to some kind of speed-accuracy trade-off. Moreover, there was a significant two-way interaction of coherency  $\times$  congruency [ $F(2, 30) = 6.6, p < 0.01, \eta_p^2 = 0.31$ ]. This suggests that accuracies in the congruent and neutral trials were higher than in the incongruent trials (both,  $p < 0.01$ ) for the coherent PLW but not for the scrambled PLW.

The results of Experiment 1 suggest that global shape affects saccade latencies, but local motion does not. This is somewhat inconsistent with a previous behavioral study (Bosbach et al., 2004) that demonstrated a congruency effect even with scrambled PLWs. In their scrambled PLW stimulus, the point lights were always displaced to

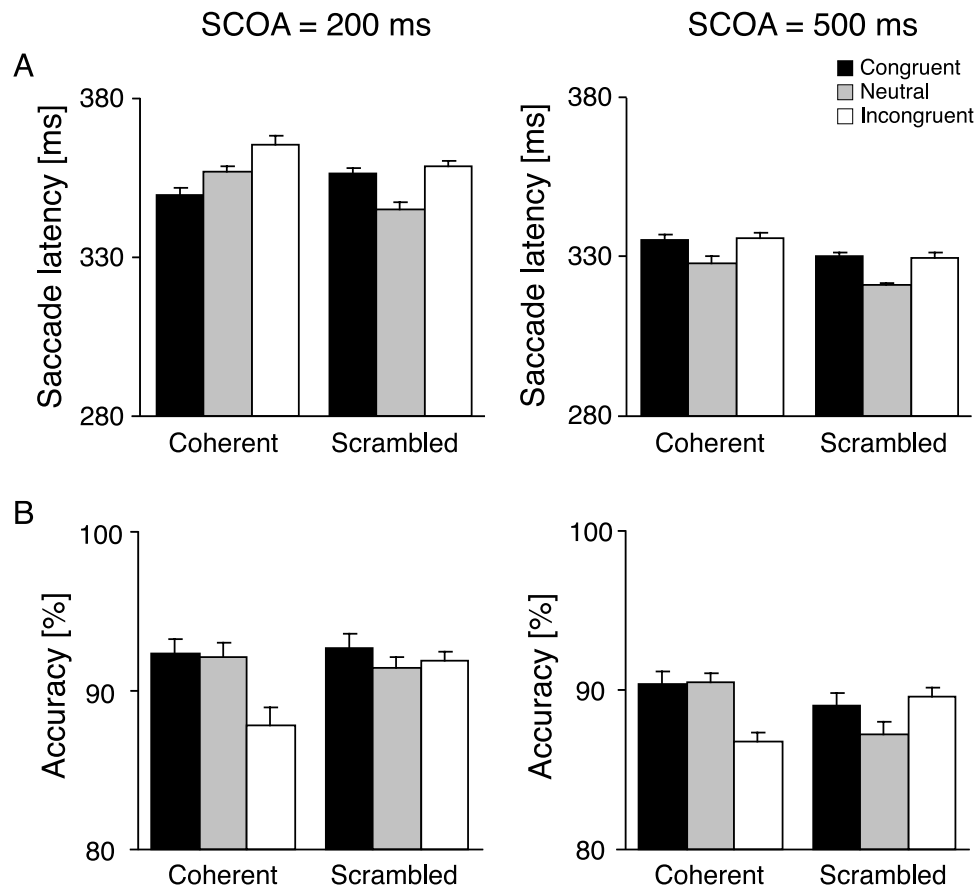


Figure 2. (A) Mean saccade latencies for correct saccades to target and (B) mean percentage of correct saccades for congruent, neutral, and incongruent trials in [Experiment 1](#). Error bars depict SEMs after subtracting from the data the inter-subject variance (Cousineau, 2005). SCOA: stimulus color onset asynchrony.

the same location, and therefore predictable across trials. Furthermore, the dot representing the right foot was kept at its original place, while the location of the left foot was shifted up by only about 10% of the walker's height. Therefore, the locations of the dots indicating the feet were approximately similar to the original coherent PLW stimulus. In contrast, in our experiment, the location of all dots was determined randomly on a trial-by-trial basis. We suspect that the difference in the predictability of the location of the feet is the reason for the discrepancy between our results and the ones found by Bosbach et al. (2004).

## Experiment 2

The second experiment was designed to investigate whether this is the case. In this experiment, we used the same coherent PLW as was used in the previous experiments but a somewhat different technique to generate the scrambled walker: Here, we did not change the location of the two dots representing the feet. However, all other dots

were scrambled by assigning random locations within the area covered by the coherent figure. Otherwise, the experiment was identical to [Experiment 1](#).

## Methods

### Participants

Twelve new observers (age range 18–29 years, mean = 19.5 years, 4 males) were recruited for [Experiment 2](#). All of them had normal or corrected-to-normal vision and received course credit for their participation.

### Stimuli and procedures

Participants were tested in two separate blocks, each associated with one type of walker (coherent or scrambled). In the scrambled PLW stimulus, we did not change the location of the two dots representing the feet. However, all other dots were scrambled by assigning random locations within the area covered by the coherent figure. Otherwise, the experiment was identical to [Experiment 1](#).

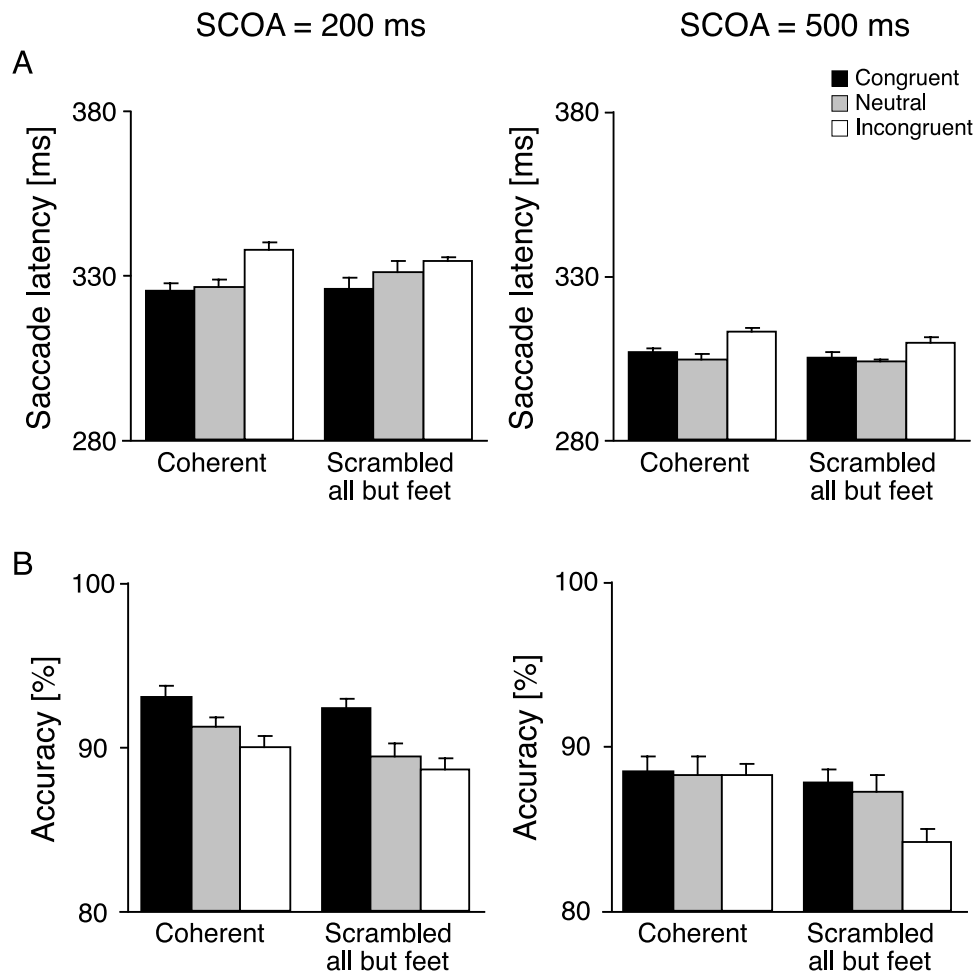


Figure 3. (A) Mean saccade latencies for correct saccades to target and (B) mean percentage of correct saccades for congruent, neutral, and incongruent trials in [Experiment 2](#). Error bars depict SEMs after subtracting from the data the inter-subject variance (Cousineau, 2005). SCOA: stimulus color onset asynchrony.

### Data analysis

For the statistical analysis, three-way ANOVAs were performed both for accuracy and for saccadic latency with coherency (coherent or scrambled), congruency (congruent, incongruent, and neutral), and SCOA (200 and 500 ms) as within-subject variables. Post hoc multiple comparisons were based on Tukey's HSD.

### Results and discussion

For the mean correct saccade latencies ([Figure 3A](#)), we found main effects of SCOA [ $F(1, 11) = 50.3, p < 0.01, \eta_p^2 = 0.82$ ] and congruency [ $F(2, 22) = 8.4, p < 0.01, \eta_p^2 = 0.43$ ]. Latencies in the 500-ms SCOA condition were shorter than in the 200-ms SCOA condition. Moreover, the latencies in the incongruent trials were longer than in the congruent ( $p < 0.01$ ) and neutral ( $p < 0.01$ ) trials. We did not find a main effect of coherency and also no interactions were found.

For the mean accuracy ([Figure 3B](#)), there were main effects of SCOA [ $F(1, 11) = 7.7, p < 0.05, \eta_p^2 = 0.41$ ] and congruency [ $F(2, 22) = 5.0, p < 0.05, \eta_p^2 = 0.31$ ]. Accuracies for congruent trials were higher than for incongruent trials ( $p < 0.01$ ), and accuracies in the 200-ms SCOA trials were higher than in the 500-ms SCOA trials ( $p < 0.05$ ). Comparing the differences in accuracy to the differences in saccade latencies, the effects of SCOA might be due to a speed–accuracy trade-off. However, saccade latencies and accuracies both add to the congruency effect with equal sign: Congruent trials feature both faster saccades and higher accuracies as compared to incongruent trials.

The results show that cues to direction contained in the local motion of the feet are as effective in their influence on the saccade task as are directional cues in the global motion-mediated shape of the walker. A comparison with the results of [Experiment 1](#), however, implies that uncertainty about their location can disrupt that effect. In the absence of global form, the cues to directionality contained in the local motion of the feet are the only available cues. One might argue that the effects

measured in our experiments are artificial and that these local cues may not play any significant role in conditions in which other information is available.

## Experiment 3

In [Experiment 3](#), we therefore used a stimulus that provides both global form and local motion cues, but with conflicting contents. [Experiment 3](#) was identical to the previous two experiments, except that we replaced the scrambled walker with a coherent walker that was played back in reversed order. This backward walking figure contains the very same motion-mediated shape as the normal, coherent, forward walker, and it faces in the same direction. The cues contained in its motion, however, point in the opposite direction and thus conflict with the cues provided by the figure's motion-mediated shape.

## Methods

### Participants

Another twelve observers (age range 18–24 years, mean = 18.8 years, 2 males) participated in [Experiment 3](#). All of them had normal or corrected-to-normal vision and received course credit for their participation.

### Stimuli and procedures

Participants were tested in two separate blocks, each associated with one type of walker (forward or backward). The experimental procedure was exactly identical to [Experiments 1](#) and [2](#).

### Data analysis

For the statistical analysis, three-way ANOVAs were performed both for accuracy and for saccadic latency with walking direction (forward or backward), congruency (congruent, incongruent, and neutral), and SCOA (200 and 500 ms) as within-subject variables. Post hoc multiple comparisons were based on Tukey's HSD. Note that, as before, we define "congruency" here in terms of the directionality provided by the global structure. The factor "coherency" is now replaced with the factor "walking direction" (forward vs. backward).

## Results and discussion

For the mean correct saccade latencies ([Figure 4A](#)), we found that saccade latencies in the conditions with conflicting cues were determined by the direction as

defined by the local motion rather than the global shape. In the statistical analysis, there was a main effect of SCOA [ $F(1, 11) = 95.8, p < 0.01, \eta_p^2 = 0.90$ ]. Latencies in the 500-ms SCOA condition were shorter than in the 200-ms SCOA condition. There was no main effect of congruency but a significant two-way interaction of walking direction  $\times$  congruency [ $F(2, 22) = 12.9, p < 0.01, \eta_p^2 = 0.54$ ]. Latencies in the incongruent trials were longer than in the congruent ( $p < 0.01$ ) and neutral ( $p < 0.01$ ) trials for the forward PLW. For the backward PLW, the latencies in the congruent trials were longer than in the neutral ( $p < 0.05$ ) and incongruent ( $p < 0.01$ ) trials.

For accuracy data ([Figure 4B](#)), there was a main effect of SCOA [ $F(1, 11) = 10.2, p < 0.01, \eta_p^2 = 0.54$ ], with accuracy for the 200-ms SCOA trials being higher than for the 500-ms SCOA trials. This again points to a speed–accuracy trade-off. The two-way interaction of walking direction  $\times$  congruency did not reach significance [ $F(2, 22) = 2.4, p = 0.11, \eta_p^2 = 0.19$ ], but the trend points in the same direction as for the latency data: for the backward walking walker, accuracy was generally higher for the "incongruent" condition, implying that accuracy relates to the local motion cues rather than to the global motion-mediated shape.

## General discussion

The current findings provide the first evidence that point-light walkers have a significant effect on overt attention comparable to previously documented effects of visual stimuli based on gaze (Kuhn & Benson, 2007; Kuhn & Kingstone, 2009; Ricciardelli et al., 2002) and hand gestures (Crostella et al., 2009). Moreover, we also show that this effect is mainly carried by the local motion of the feet. It becomes masked, however, when the location of the feet is no longer predictable. When incongruent with the cued side, the direction indicated by the local motion of the feet increased saccade latencies and induced more errors. We discovered this in [Experiment 2](#) through the use of a point-light display with all but the feet scrambled, resolving the problem of conventional scrambled biological motion: a confound between deprivation of coherent shape and the creation of uncertainty in position. In [Experiment 3](#), we put the cues provided by local motion signatures and global motion-mediated shape in direct conflict. We found that local motion dominated in its effect on saccade latency and accuracy over directional cues contained in the overall shape of the walker.

Our results also resolve an apparent conflict between two previous studies. While Bosbach et al. (2004), as discussed above, did find that their scrambled walker triggered directionality effects, another study from the same year (Thornton & Vuong, 2004) did not show any "incidental" processing of local biological motion. Using

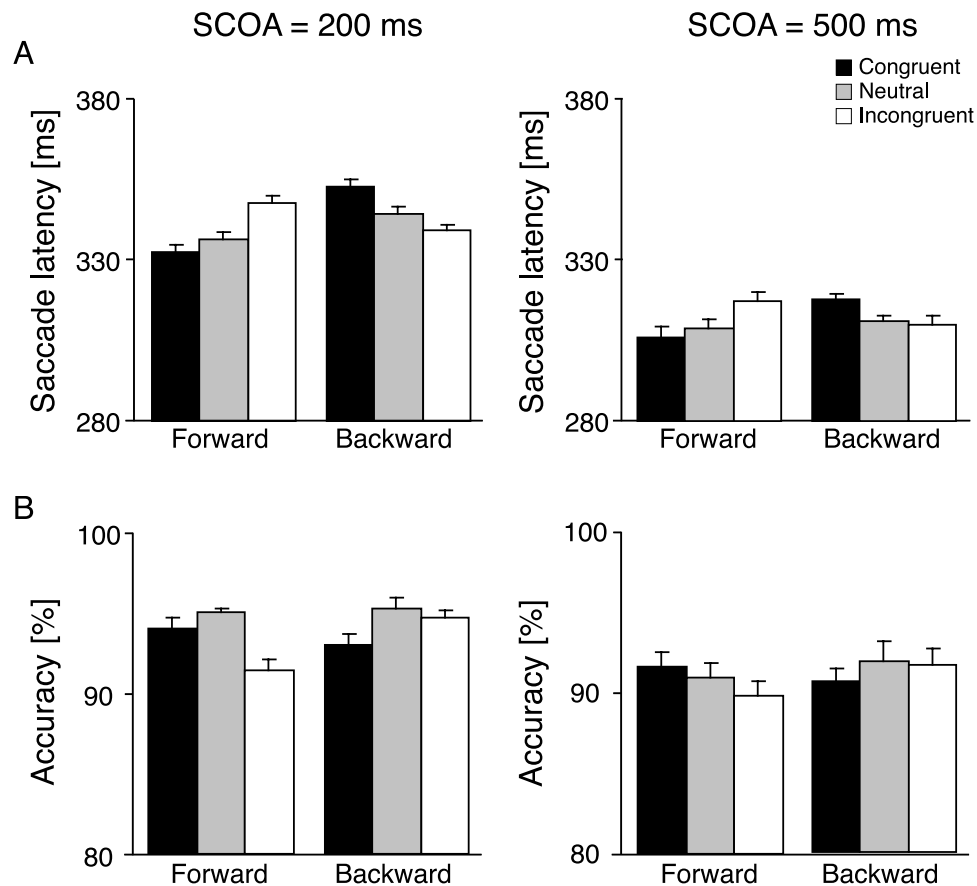


Figure 4. (A) Mean saccade latencies for correct saccades to target and (B) percentage of correct saccades for congruent, neutral, and incongruent trials in Experiment 3. Here, “congruency” was defined by the direction of the global shape of the walker. Error bars depict SEMs after subtracting from the data the inter-subject variance (Cousineau, 2005). SCOA: stimulus color onset asynchrony.

the flanker paradigm, the authors observed a congruency effect only for the coherent PLWs and not for the scrambled PLWs, which was consistent with the result of our Experiment 1. As in our first experiment, Thornton and Vuong (2004) completely randomized the locations of the dots representing the PLW before each trial. By contrast, Bosbach et al. only randomized the location of the dots of their PLW once over the entire experiment, and the dots representing the feet were in approximately the same location as in the original coherent PLW stimulus. In our Experiment 2, the feet were always in the same vertical location, and our pattern of results was more consistent with Bosbach et al. The apparent conflict can therefore be explained by the different ways in which the two research groups scrambled their stimuli and the consequent differences in the predictability of the relevant feet marker location.

Regarding the effect of the duration of the stimulus color onset asynchrony (SCOA), the saccade latency decreased with increasing SCOA. This was consistent with the findings of Bosbach et al. (2004) and was also observed in the eye movement experiment using gaze and arrow stimuli (Kuhn & Kingstone, 2009). We found a pronounced congruency effect for the coherent PLW in all

experiments and for the scrambled PLW (Experiment 2), even for SCOAs as short as 200 ms. Previous electrophysiological studies in macaques reported that the cells in the posterior region of the superior temporal polysensory area (STP) showed sensitivity to the locomotive direction of the PLW, and the response was found at around 100 ms after stimulus onset (Oram & Perrett, 1994). Viewing of point-light displays by humans elicits similarly short responses (~300 ms) in studies using both magnetoencephalography (Pavlova, Lutzenberger, Sokolov, & Birbaumer, 2004) and event-related potentials (Hirai, Fukushima, & Hiraki, 2003; Jokisch, Daum, Suchan, & Troje, 2005). Our study shows that short presentation times are also sufficient for directional cues in the stimulus to affect saccade latencies.

Congruency effects seem to be a bit weaker in the 500-ms SCOA condition than in the 200-ms SCOA. In Experiment 1, they are in fact entirely absent for the longer SCOAs even for coherent walkers. We do not know why this is the case, but we point out that our observation is consistent with the data obtained by Bosbach et al. (2004) who used only SCOAs shorter than 500 ms. In contrast to Experiment 1, we observe moderate



congruency effects in the equivalent conditions in [Experiments 2](#) and [3](#). If the difference is not just due to measurement errors and experimental noise, we may assume that the context provided by the different non-coherent conditions in the three experiments affects behavior in the condition in which we show coherent walkers. If that was the case, we should observe the difference only for those observers that first saw the non-coherent walkers and after that the coherent ones. The observers who did the coherent conditions first, in contrast, should not be affected. In order to test that, we included the order of the two blocks into an ANOVA, searching for an interaction between the factors Order and Congruency. For all three experiments, we did not find any traces of such an interaction. Lacking a better explanation, we therefore assume that the absence of a coherency effect in the 500-ms/coherent condition in [Experiment 1](#) is simply due to measurement noise.

Because we included a frontal walker as a neutral condition, we can also analyze the effect of congruency in terms of facilitation and cost. A comparison of saccade latencies between congruent and neutral distractors provides us with an index of facilitation for congruency, while a comparison between incongruent and neutral distractors provides us with information about the costs of incongruency (Kuhn & Benson, 2007; Langdon & Smith, 2005). Here, for the coherent PLW, saccade latencies on incongruent trials were longer than on congruent trials, but in all experiments, the latencies on congruent trials were not significantly shorter than on neutral trials. For the scrambled PLW, when the feet location was changed on a trial-by-trial basis, there was no cost of incongruency ([Experiment 1](#)); however, when the feet motion was in the original vertical location, a similar pattern to that seen with the coherent PLW was observed ([Experiment 2](#)). The patterns of saccade latency facilitation and cost we observed differed from studies on the saccade task using eye gaze (Koval, Thomas, & Everling, 2005) and both eye gaze and arrow stimuli (Kuhn & Benson, 2007): Koval et al. demonstrated that the saccade latencies for congruent trials were significantly faster than neutral and incongruent trials, but that saccade latencies for incongruent trials were not different from the neutral trials, thus both eye gaze and arrow distractors resulted in facilitation but not cost effects. Kuhn and Benson found a similar pattern in the saccade latency due to eye gaze: facilitation without cost, or at least minimal cost. There is previous evidence, however, that biological motion stimuli may produce a qualitatively different pattern of cost and facilitation compared with other social stimuli that contain direction cues. Consistent with our current finding, in a flanker paradigm, Thornton and Vuong (2004) found that reaction times in the neutral trials were indistinguishable from congruent trials, but incongruent trials led to slower responses.

The neural mechanisms underlying the current phenomenon still remain unclear. However, electrophysiological work in macaque monkeys has shown that the upper and

lower banks of the rostral superior temporal sulcus (STS) region contains cells sensitive to displays of both forward and backward walking (Barracough, Xiao, Oram, & Perrett, 2006; Oram & Perrett, 1994, 1996). More recent neuroimaging and electrophysiological studies have localized regions that may be connected to the local motion aspect of biological motion processing. In an fMRI study in humans, Jastorff and Orban (2009) identified a dorsal region that included the posterior inferior temporal sulcus and the posterior superior temporal sulcus (pSTS) that showed selectivity to local motion, by subtracting biological motion from rigidly translating point lights with the same global form. Consistent with these findings, a recent electrophysiological study revealed that there are two types of neurons in the STS region: “motion” neurons and “snapshot” neurons (Vangeneugden, Pollick, & Vogels, 2009). “Snapshot” neurons are primarily located in the ventral bank of the STS, and their response is equally strong for static and dynamic presentations. “Motion” neurons are primarily located in the dorsal bank of the STS, and their activation is modulated by the motion patterns of the action. This dissociation may reflect the one between the processing of global motion-mediated shape, on the one hand, and local motion invariants, on the other hand.

In conclusion, our data show that the local invariants that convey directionality even from point-light stimuli without any defined shape also affect overt attention as reflected in the saccade latencies to unrelated targets. The finding supports the idea that the kinematics characteristic for the feet of a terrestrial animal in legged locomotion provides visual saliency that helps to detect animals in the visual environment.

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