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Searching for Life Motion Signals: Visual Search Asymmetry in Local but Not Global Biological-Motion Processing

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Abstract

The visual search paradigm has been widely used to study the mechanisms underlying visual attention, and search asymmetry provides a source of insight into preattentive visual features. In the current study, we tested visual search with biological-motion stimuli that were spatially scrambled or that represented feet only and found that observers were more efficient in searching for an upright target among inverted distractors than in searching for an inverted target among upright distractors. This suggests that local biological-motion signals can act as a basic preattentive feature for the human visual system. The search asymmetry disappeared when the global configuration in biological motion was kept intact, which indicates that the attentional effects arising from biological features (e.g., local motion signals) and global novelty (e.g., inverted human figure) can interact and modulate visual search. Our findings provide strong evidence that local biological motion can be processed independently of global configuration and shed new light on the mechanisms of visual search asymmetry.

Keywords

visual search, biological motion, local, global, attention

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The visual search paradigm has been widely used as a tool to uncover visual mechanisms underlying selective attention (Treisman & Gelade, 1980; Wolfe, 1998). In a standard visual search task, participants are required to look for a predefined target among a set of distractors in a display. Search efficiency can be estimated as the slope of response times as a function of the number of items in the display. In some cases, search seems to be effortless (resulting in a very shallow slope), but in other cases, searching for a target among distractors can be very inefficient (resulting in a very steep slope). A robust phenomenon related to search efficiency is search asymmetry. Search asymmetry is defined as a change in search efficiency that occurs when target-distractor mapping is reversed (Treisman & Gormican, 1988; Treisman & Souther, 1985; Wolfe, 2001). That is, search for A among B is more efficient than search for B among A. According to Treisman and Souther (1985), it is easier to find a target defined by the presence of a basic preattentive feature (stimulus A) than to find a target defined by the absence of that feature (stimulus B). Therefore, search asymmetry is an important index, as it offers a diagnostic to identify potential preattentive visual features.

Search asymmetries can be observed from the presence versus absence of low-level features, such as color, orientation, and motion information (Treisman & Gormican, 1988; Wolfe, 2001). Similarly, there are visual search asymmetries associated with high-level visual information processing. For example, participants detect an unfamiliar letter among familiar ones more quickly than they detect a familiar letter among unfamiliar ones (Wang, Cavanagh, & Green, 1994). Similarly, Wolfe (2001) reported that human observers found the inverted elephant among upright elephants more efficiently than the other way around. These visual search asymmetries are interpreted as arising from processing of novel versus familiar visual information, because novelty information potentially has preattentive status as a basic feature (Wolfe, 2001).

When upright and inverted facial stimuli are used in a visual search task, however, the results are more complicated. A chimpanzee performed better in searching for an upright

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human face among inverted faces than in searching for an inverted face among upright faces (Tomonaga, 2001, 2007). This visual search asymmetry is the opposite of what would be predicted from the preattentive novelty feature; because an inverted stimulus is novel, one might expect better performance in search for an inverted target than in search for an upright target. Moreover, some other studies found that human observers showed no search asymmetries for upright versus inverted faces (Kuehn & Jolicoeur, 1994; Nothdurft, 1993). These findings from studies using facial stimuli seem to be inconsistent with those from studies using other common object stimuli, such as letters. However, given that the upright human face is a special visual pattern with obvious biological significance, it is possible that biologically significant information also serves as a preattentive visual feature and that the attentional effect arising from biological meaningfulness of the upright face might offset or even override the novelty effect from the inverted face (Jiang, Costello, & He, 2007). Therefore, the findings that patterns of visual search behavior differ between some types of objects (e.g., letters) and faces could reflect the interaction of biological significance and novelty.

To test this possibility, we adopted a type of biological-motion stimulus, the point-light walker, for use in a visual search task. Like the human face, biological motion is a biologically meaningful visual pattern. People are remarkably adept at recognizing the motion of biological entities in complex visual scenes, even when these entities are portrayed by a handful of point lights attached to the head and major joints (Johansson, 1973). It has been demonstrated that observers can readily recognize the action (Dittrich, 1993; Norman, Payton, Long, & Hawkes, 2004), gender (Kozlowski & Cutting, 1977, 1978; Troje, 2002), and identity (Cutting & Kozlowski, 1977; Troje, Westhoff, & Lavrov, 2005) information conveyed by point-light biological motion. Even peripherally presented point-light walkers that participants are told to ignore can be incidentally processed to a level sufficient to affect the perception of the walking direction of a central target walker (Thornton & Vuong, 2004). However, perception of biological motion is strongly impaired if the point-light displays are shown upside down (Pavlova & Sokolov, 2000; Proffitt & Bertenthal, 1990; Sumi, 1984). The inversion effect in biological motion has often been attributed to impaired processing of global configural information (Beintema & Lappe, 2002; Bertenthal & Pinto, 1994; Neri, Morrone, & Burr, 1998).

Notably, it was shown recently that there is another inversion effect that relies on local motion signals (Troje & Westhoff, 2006). Observers can retrieve information about the walking direction of upright but not inverted point-light displays of humans and animals when all of the points are spatially scrambled and the global configural information is removed; this effect seems to rely primarily on the motion of the feet (Chang & Troje, 2009; Saunders, Suchan, & Troje, 2009; see also Mather, Radford, & West, 1992). The dissociation between the global configuration and local motion information in biological motion provides a unique opportunity to examine the attentive features of biological motion, as well as the nature of visual search asymmetry in high-level information processing. Both global upright and local upright biological motion have processing advantages compared with inverted biological motion. More important, unlike global biological motion, which is more familiar in upright than in inverted stimuli, upright local biological motion and inverted local biological motion are equally unfamiliar to naive observers.

In the study reported here, we examined if there are search asymmetries between biological-motion patterns and their inverted counterparts when the global configuration of the biological motion is kept intact (global condition) and when it is disrupted (local condition). We hypothesized that if local motion signals indeed have a basic attentive feature, there would be a significant visual search asymmetry in the local condition. In the global condition, however, novelty (i.e., an inverted walker) might also have an effect, which to some degree would offset the attentional effect of biological significance (from upright biological motion); therefore, the final results would depend on which effect (biological significance or novelty) contributes more to search efficiency.

Method

Participants

Eight participants (4 female, 4 male) whose ages ranged from 21 to 25 years took part in Experiment 1 and Experiment 2. Six of these individuals and 2 new participants took part in Experiment 3. All had normal or corrected-to-normal vision and gave written, informed consent in accordance with procedures and protocols approved by the institutional review board of the Institute of Psychology, Chinese Academy of Sciences. All participants were naive to the purpose of the experiments.

Stimuli

Stimuli were generated and displayed using MATLAB (The Mathworks, Natick, MA) together with the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). Point-light biological-motion sequences, which were created by videotaping a walking actor, were adopted from Vanrie and Verfaillie (2004). The segments were digitized, and the head and joint positions in each frame were encoded as motion vectors with initial starting positions (Vanrie & Verfaillie, 2004). Six exemplars with different viewpoints (left 90°, 60°, and 30° and right 90°, 60°, and 30°) were used in the experiments. Scrambled biological-motion sequences were created by randomizing the starting position of each point within the region approximately covered by the intact biological-motion sequence. In the scrambled biological-motion sequences, the local motion components remained unchanged; the global form and global pattern information were entirely removed. Feet-only sequences were created by isolating the two point lights of the ankles from the original sequences. Inverted biological-motion sequences (i.e., the intact, scrambled, and feet-only versions) were created by mirror-flipping all of the motion sequences vertically. The inversion disrupted any meaningful local biological-motion information, although the global configuration from intact biological motion could still be perceived.

Procedure and data analysis

Stimuli were presented in white on a gray background, and the viewing distance was 80 cm. Each trial began with a search display of three, six, or nine items. Their positions were randomly chosen from a set of nine possible positions that were evenly spaced on an imaginary circle with an eccentricity of 7.1° of visual angle (see Fig. 1). For each participant and trial, the items were all randomly selected from the set of six exemplars. Each individual motion stimulus subtended approximately 2.75° × 3.15° of visual angle. A display remained on the screen until the participant responded. On half of the trials, one of the items was a target and the rest were distractors. On the remaining trials, all of the items were distractors, and no target was presented. Participants were required to press one of two keys on a standard keyboard to indicate whether the target was present or absent. They were instructed to respond as quickly as possible while minimizing errors. A beep was provided as feedback if the response was an error. The intertrial interval was 1,000 ms. Throughout each experiment, a central cross was always displayed in the center of the screen, and observers were asked to fixate on the central cross at the beginning of each trial.

The three experiments were run on separate days. Before each experiment, participants were shown a biological-motion sequence and its inverted counterpart side by side so that they would be clear as to the nature of the stimuli that would be displayed in the experiment. In Experiment 1, the upright scrambled biological-motion sequences were paired with the inverted scrambled biological-motion sequences. In Experiment 2, the upright intact biological-motion sequences were paired with the inverted intact biological-motion sequences. In Experiment 3, the upright feet-only motion sequences (with only the two point lights of the ankles) were paired with the inverted ones. In all experiments, participants completed two blocks of trials—one in which they searched for an upright biological-motion sequence among inverted sequences and one in which they searched for an inverted biological-motion sequence among upright sequences. At the beginning of each block, participants were given practice trials until they were familiar with the task and the stimuli. Each block consisted of 120 trials, with a short rest break after every 40 trials. The 120 trials comprised 20 trials in each of six conditions created by crossing set size (3, 6, or 9) and target presence (present or absent). Test trials were presented in a new random order for each participant. For half of the participants, the targets were upright in the first block and inverted in the second block; for the other half of the participants, this order was reversed.

Search times were entered into a 3 × 2 × 2 repeated measures analysis of variance (ANOVA) with three within-subjects factors: set size (3, 6, or 9), target orientation (upright or inverted), and target presence (present or absent). The search slopes were also analyzed with a repeated measures

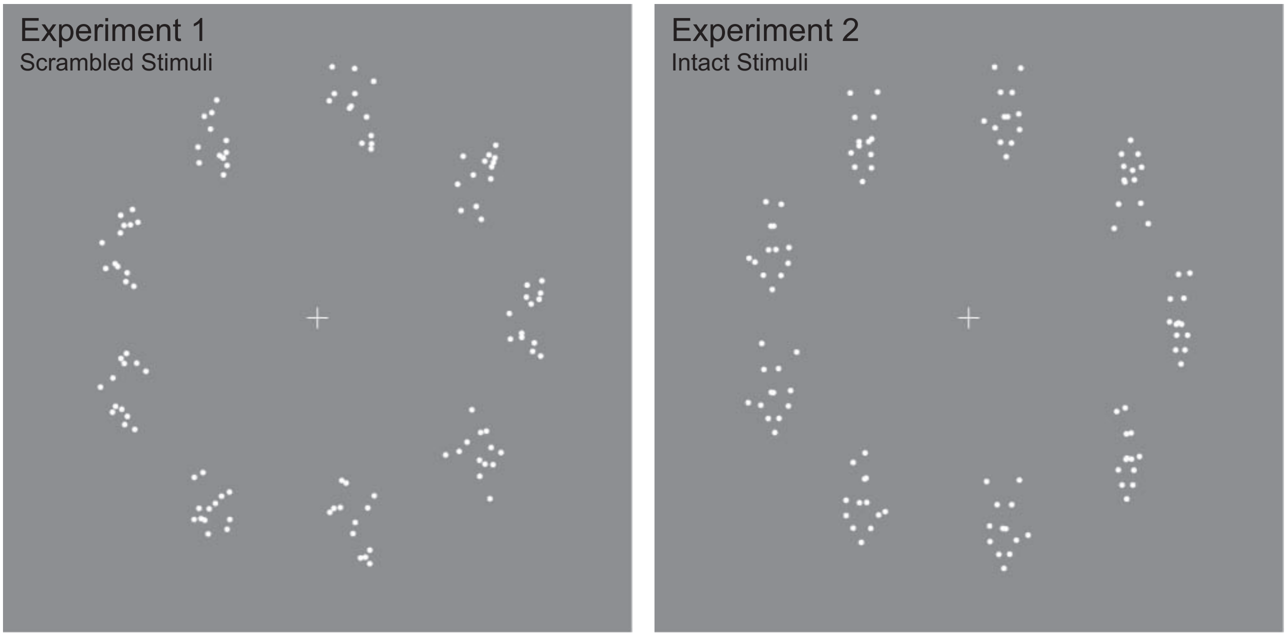

Fig. 1. Static frames illustrating the stimuli in Experiments 1 and 2. Each experiment used two types of point-light biological-motion stimuli: scrambled upright and scrambled inverted biological-motion stimuli in Experiment 1 (left panel) and intact upright and intact inverted biological-motion stimuli in Experiment 2 (right panel). In each search display, the target and distractors appeared at randomly selected positions on an imaginary circle. Observers were asked to detect whether the target was present or absent as quickly as possible while minimizing errors.

ANOVA with within-subjects factors of target orientation and target presence.

Results

Experiment 1: visual search asymmetry in scrambled-biological-motion processing

The results from Experiment 1 are plotted in Figure 2, which shows the mean search time as a function of set size (3, 6, or 9). Data for each combination of target orientation (upright or inverted) and target presence (present vs. absent) are plotted separately. Clearly, observers' search time increased as set size increased, $F(2, 14) = 39.70$, $p < .001$. The interaction of set size, target orientation, and target presence was also significant, $F(2, 14) = 4.53$, $p < .05$. More important, in the target-present condition, there was a significant main effect of target orientation, $F(1, 7) = 9.23$, $p < .05$. In other words, search time for an upright scrambled biological-motion sequence among inverted scrambled biological-motion sequences was faster than search time for an inverted sequence among upright sequences, a pattern that suggests a significant visual search asymmetry due to biological significance (upright vs. inverted biological motion). In the target-absent condition, there was no significant difference between the two target orientations, $F(1, 7) = 0.10$, $p > .1$. There was no evidence of a speed-accuracy trade-off.

As expected, search slopes were steeper for target-absent trials than for target-present trials, $F(1, 7) = 13.75$, $p < .01$ (see Table 1). There was a significant interaction between target orientation and target presence, $F(1, 7) = 6.70$, $p < .05$. A significant search asymmetry between the upright and inverted scrambled biological-motion stimuli was evident in search slopes when the target was present, $t(7) = 3.13$, $p < .05$. That is, searching for an upright target among inverted distractors (209 ms/item) was much more efficient than searching for an inverted target among upright distractors (391 ms/item).

Experiment 2: no search asymmetry in global-biological-motion processing

The results from Experiment 2 are shown in Figure 2. There was a significant main effect of set size, $F(2, 14) = 84.13$, $p < .001$; search time increased as set size increased. In the target-present condition, there was no significant visual search asymmetry (search for an upright target among inverted distractors vs. search for an inverted target among upright distractors), $F(1, 7) = 0.11$, $p > .1$. In other words, there was no noticeable advantage in looking for an upright biological-motion target (biologically meaningful stimulus) compared with looking for an inverted biological-motion target (novelty stimulus), a result similar to what has been found in studies of visual search for upright versus inverted face stimuli (Kuehn & Jolicoeur, 1994; Nothdurft, 1993). In the target-absent condition, there was a significant main effect of distractor orientation, $F(1, 7) = 9.10$, $p < .05$; observers were faster to exclude upright distractors than to exclude inverted distractors. There was no evidence of a speed-accuracy trade-off.

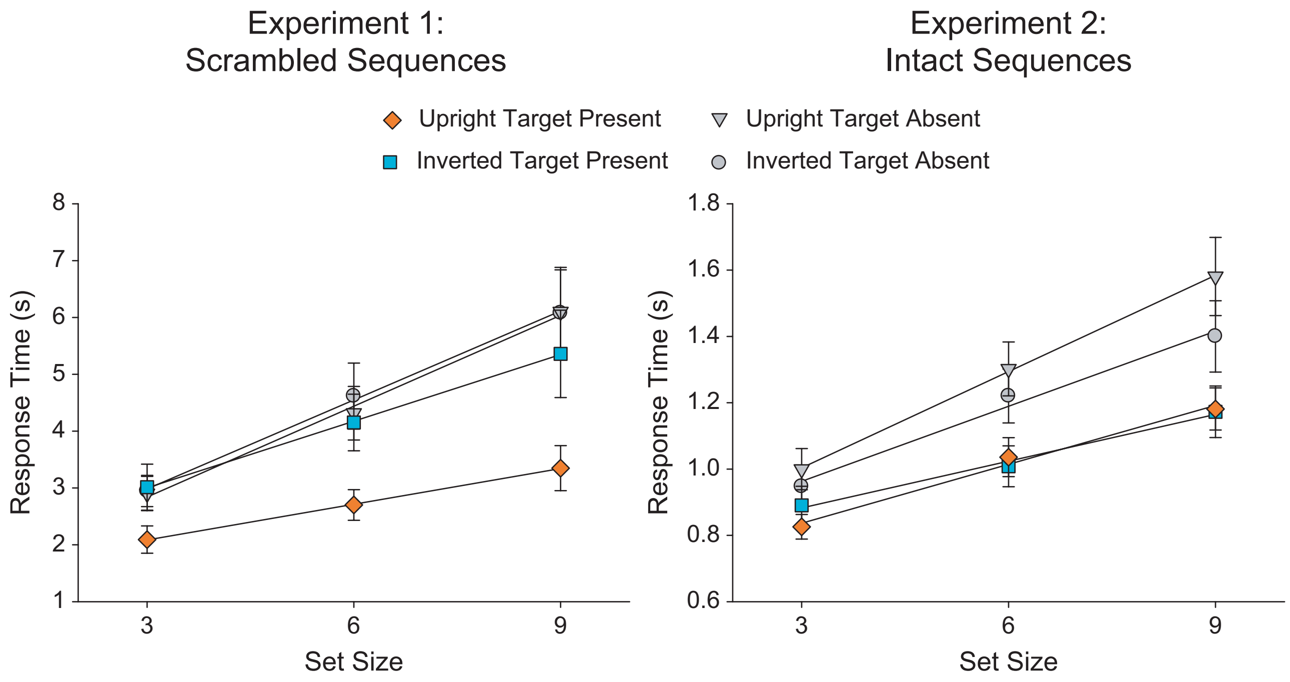

Fig. 2. Visual search results from Experiments 1 and 2. In Experiment 1 (left panel), the biological-motion sequences were scrambled, and in Experiment 2 (right panel), the sequences were intact. Mean response times are plotted as a function of set size (3, 6, or 9), target orientation (upright or inverted), and target presence (present or absent). Error bars show standard errors.

Table 1. Search Slopes in the Experiments

Experiment and target orientation	Target present	Target absent
Experiment 1: scrambled stimuli		
Upright targets	209.48 (32.6)	532.8 (92.0)
Inverted targets	390.83 (68.3)	521.93 (94.4)
Experiment 2: intact stimuli		
Upright targets	59.23 (5.81)	96.84 (10.7)
Inverted targets	47.01 (11.4)	75.51 (8.68)
Experiment 3: feet-only stimuli		
Upright targets	262.33 (56.2)	445.03 (45.05)
Inverted targets	396.31 (60.21)	686.66 (97.39)

Note: The table presents mean slopes (in milliseconds/item), with standard errors in parentheses.

Search slopes were steeper in target-absent trials than in target-present trials, $F(1, 7) = 13.40$, $p < .01$ (see Table 1). Although the search slopes were much shallower than those in Experiment 1 because of the presence of global biological-motion configurations, there was no difference in search slopes between the upright- and inverted-target conditions when the target was present, $t(7) = 1.11$, $p > .1$. In an analysis combining Experiments 1 and 2, the interaction between global configuration of biological motion (intact or scrambled) and target orientation (upright or inverted) was highly significant, $F(1, 7) = 11.84$, $p < .05$. Thus, the visual search asymmetry was revealed only in local, but not global, biological-motion processing.

Experiment 3: visual search asymmetry in local-biological-motion processing

The results from Experiment 3 were very similar as those from Experiment 1. In the target-present condition, there was a significant main effect of target orientation, $F(1, 7) = 5.44$, $p < .05$, reflecting the fact that search time for an upright target among inverted distractors was faster than search time for an inverted target among upright distractors. A significant search asymmetry between the upright and inverted stimuli was also evident in search slopes when the target was present (262 ms/item vs. 396 ms/item; see Table 1), $t(7) = 2.42$, $p < .05$. These results confirmed the findings from Experiment 1 and provide strong evidence for automatic processing of local biological-motion signals that is independent of global-configuration processing.

Discussion

The human visual system is highly sensitive to biological motion and is capable of extracting complex information—including action, gender, and identity—from it (Cutting & Kozlowski, 1977; Dittrich, 1993; Johansson, 1973; Kozlowski & Cutting, 1977, 1978; Norman et al., 2004; Troje, 2002; Troje et al., 2005). One recent study by Thornton and Vuong (2004) showed that global biological motion can even be processed incidentally. The processing advantage for global upright biological motion compared with global inverted biological motion, however, did not produce a more efficient search. In other words, search time for an upright biological-motion stimulus among inverted biological-motion stimuli was not faster than search time for an inverted biological-motion stimulus among upright biological-motion stimuli. Indeed, our results are consistent with those from previous studies using upright and inverted faces as search targets and distractors (Kuehn & Jolicoeur, 1994; Nothdurft, 1993).

Previous studies have shown that it is easier to detect novel items among familiar distractors than to detect familiar items among novel distractors (Malinowski & Hubner, 2001; Shen & Reingold, 2001; Wang et al., 1994; Wolfe, 2001), particularly when the stimuli have no obvious biological meaningfulness or biological significance. We hypothesize that the attentional effect of biological meaningfulness or biological significance (arising from upright biological-motion signals) in visual search might have been offset in the current study by some other factors, such as novelty (arising from inversion of human figures). Our results from target-absent trials in Experiment 2 indeed showed that observers' response times were faster when distractors were upright biological-motion patterns rather than inverted ones. This suggests that upright biological-motion patterns can be processed more rapidly than inverted biological-motion patterns when they serve as distractors, a pattern that has been observed in previous studies (Pavlova & Sokolov, 2000; Sumi, 1984). However, the faster rejection of upright distractors was not reflected in the target-present trials, a result indicating that multiple factors were involved in the visual search.

In order to test our hypothesis, we used spatially scrambled biological-motion stimuli (upright and inverted) in the current study. Because the scrambled upright and inverted biological-motion stimuli were both unfamiliar to the naive observers, a novelty bias would not differentially affect search for these two types of stimuli. Indeed, we found a robust search asymmetry for upright versus inverted scrambled biological motion. It was easier for observers to detect an upright scrambled biological-motion target among inverted scrambled biological-motion distractors than for them to detect an inverted scrambled biological-motion target among upright scrambled biological-motion distractors. Moreover, when the stimuli consisted of only the two point lights of the ankles, which obviously had no global configuration but clearly conveyed local biological-motion information, results were very similar to those observed with scrambled biological motion (i.e., a significant visual search asymmetry between upright vs. inverted local biological-motion signals). In a supplemental experiment, however, we found that this search asymmetry disappears for stimuli that are identical to the feet-only sequences except that critical biological information (e.g., motion acceleration and motion phase) is removed (see the

Supplemental Material available online for more detail). Our findings are in line with recent studies on local biological-motion processing (Chang & Troje, 2009; Saunders et al., 2009; Troje & Westhoff, 2006) and suggest that local biological motion, independent of global configuration, may contain specific life motion signals.

Motion of biological entities consists of both local and global components. Most previous studies have emphasized the contribution of global form to biological-motion perception (Beintema & Lappe, 2002; Bertenthal & Pinto, 1994; Chatterjee, Freyd, & Shiffrar, 1996; Lange, Georg, & Lappe, 2006; Shiffrar, Lichtey, & Chatterjee, 1997). Troje and his colleagues have suggested that biological-motion perception should instead be regarded as a multilevel phenomenon in which each level makes distinct contributions (Chang & Troje, 2009; Saunders et al., 2009; Troje, 2008; see also Thornton, Pinto, & Shiffrar, 1998). Given that local biological motion alone can affect visual search, it is important to emphasize the role of local motion signals in biological motion perception. Taken together, our results provide strong evidence for automatic preattentive processing of local biological-motion signals that is independent of global-configuration processing, and suggest that visual search in our displays showing global biological motion was modulated by significant biological features (e.g., local motion signals) as well as global novelty (e.g., inverted human figures). Our results suggest that biological significance and global novelty may also play important roles in other visual search tasks using visual patterns that are complex yet have obvious biological significance as search items, such as faces.

In summary, this study demonstrated a significant visual search asymmetry in the processing of local biological motion, suggesting that local biological-motion signals can act as a basic attentive feature in visual search. This search asymmetry, however, was not found with the processing of global biological motion, a result that could have been due to the interaction of multiple factors, including biological significance (e.g., local biological-motion signals) and global novelty (e.g., inverted human figure). Our findings provide further evidence for the processing of local biological motion and shed new light on the mechanisms of visual search asymmetry.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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Supplemental Material

Additional supporting information may be found at http://pss.sagepub.com/content/by/supplemental-data

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