BRIEF REPORT

Life motion signals modulate visual working memory

Suqi Huang[1,2,3] · Yiping Ge[1,2,3] · Li Wang[1,2,3] · Yi Jiang[1,2,3]

Abstract

Previous research has demonstrated that biological motion (BM) cues can induce a reflexive attentional orienting effect, a phenomenon referred to as *social attention*. However, it remains undetermined whether BM cues can further affect higher-order cognitive processes, such as visual working memory (WM). By combining a modified central pre-cueing paradigm with a traditional WM change detection task, the current study investigated whether the walking direction of BM, as a non-predictive central cue, could modulate the encoding process of WM. Results revealed a significant improvement in WM performance for the items appearing at the location cued by the walking direction of BM. The observed effect disappeared when the BM cues were shown inverted, or when the critical biological characteristics of the cues were removed. Crucially, this effect could be extended to upright feet motion cues without global configuration, reflecting the key role of local BM signals in modulating WM. More importantly, such a BM-induced modulation effect was not observed with inanimate motion cues, although these cues can also elicit attentional effects. Our findings suggest that the attentional effect induced by life motion signals can penetrate to higher-order cognitive processes, and provide compelling evidence for the existence of "life motion detector" in the human brain from a high-level cognitive function perspective.

Keywords Biological motion · Working memory · Social attention · Life motion detector

Introduction

Humans and various other vertebrates are extremely sensitive to the motions of biological entities in the environment, which is essential for species survival (Blake, 1993; Dittrich et al., 1998; Lorenzi & Vallortigara, 2021; Regolin et al., 2000). Previous research has demonstrated that observers can effortlessly distinguish biological motion (BM) signals amidst complex visual scenes, even when presented using only a few point lights attached to the head and major joints of a person (Johansson, 1973). Many biological attributes including identity, action, and mental state are readily identifiable through such simplified point-light BM stimuli (Brooks et al., 2008; Dittrich, 1993; Johnson et al., 2011; Loula et al., 2005; Manera et al., 2010). Among these, walking direction is a particularly important attribute of BM as it conveys the disposition and intention of another living creature. It has been well documented that walking direction can be accurately discriminated when the point-light displays are embedded in dynamic visual noise (Bertenthal & Pinto, 1994; Thurman & Grossman, 2008), presented in the peripheral vision (Thompson et al., 2007), or processed incidentally (Thornton & Vuong, 2004). Developmental studies have further revealed that the ability to detect BM direction emerges early in life. Infants as young as 6 months of age can discriminate the walking direction of an upright point-light walker (Kuhlmeier et al., 2010). Moreover, newly hatched chicks exhibit spontaneous sensitivity to BM direction despite being visually naive (Vallortigara et al., 2005). Notably, such intrinsic sensitivity to BM walking direction can further affect human behavioral responses. It has been demonstrated that BM cues can trigger reflexive attentional orienting (Shi et al., 2010; Yuan et al., 2022). This effect has been observed not only in adults but also in preschool children and infants as young as 6 months of age (Bardi

✉ Li Wang
wangli@psych.ac.cn

1 State Key Laboratory of Brain and Cognitive Science, CAS Center for Excellence in Brain Science and Intelligence Technology, Institute of Psychology, Chinese Academy of Sciences, 16 Lincui Road, Chaoyang District, Beijing 100101, China

2 Department of Psychology, University of Chinese Academy of Sciences, 19A Yuquan Road, Beijing 100049, China

3 Chinese Institute for Brain Research, 26 Science Park Road, Beijing 102206, China

et al., 2015; Zhao et al., 2015). In addition, this reflexive attentional orienting effect can even be induced by local BM cues (i.e., the motion of the feet) (Wang et al., 2014).

Following the attention to items, deeper cognitive processes typically ensue, including the recognition of item characteristics and subsequent memory encoding. Here, we asked whether and to what extent the BM-mediated attentional orienting can affect high-level cognitive processes, particularly working memory (WM). WM is regarded as a memory system with limited capacity, which can temporarily maintain information and support other higher-order cognitive functions (Baddeley, 2003, 2012). It is well known that attention and WM are intimately linked (Cowan, 1995; Gazzaley & Nobre, 2012; Kane et al., 2001; Oberauer, 2009). In particular, symbolic spatial cues, such as arrows, have the potential to guide attention and improve the possibility of remembering items appearing at the location of attention (Griffin & Nobre, 2003; Li & Saiki, 2015; Tanoue et al., 2013). It is worth mentioning that these cues have predictability about the location where memory items appear. Meanwhile, non-predictive BM cues prompt unique reflexive social attention distinct from the non-social attention induced by symbolic cues (Shi et al., 2010; Wang et al., 2020; Yu et al., 2020). Recent studies have demonstrated the special role of BM information in WM storage (Ding et al., 2015; Lu et al., 2016), yet it remains unclear whether and how BM, as a non-predictive cue, exerts an impact on WM.

To address this issue, the present study investigated whether BM stimuli, as pre-cues, can modulate the encoding process of WM. To achieve this aim, we employed a modified central cueing paradigm in conjunction with a traditional WM change detection task. Specifically, point-light BM stimuli were adopted as non-predictive central cues, and participants were required to immediately perform a change detection task after viewing the central cue. We also utilized feet motion sequences as central cues to further explore the potential impact of local BM cues on WM performance. In addition, we employed a non-predictive inanimate low-level motion cue to verify that the modulation effect on WM, if observed, is specifically elicited by life motion signals.

Methods

Participants

A total of 120 participants (aged between 18 and 31 years, M_{age} = 23.83 years) took part in the study. Sixteen (11 females) participated in Experiment 1, 16 (12 females) in Experiment 2, 16 (11 females) in Experiment 3, 24 (13 females) in Experiment 4, 24 (15 females) in Experiment 5, and the remaining 24 (13 females) in Experiment 6. All participants had normal or corrected-to-normal vision and

were naive to the purpose of the study. They all 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.

To ensure adequate power, the sample size was a priori determined by a power analysis using G*Power (Version 3.1.9.2; Faul et al., 2009). A sample size of at least 14 participants would afford 80% power to detect a medium-high attentional effect (Cohen's f = 0.30) induced by intact BM cues, which was found in a previous study with a similar design (Shi et al., 2010). We increased the sample size to 16 per experiment to adequately detect the potential interactions in Experiments 1–3. Meanwhile, a two-tailed power analysis based on a medium-high attentional effect (Cohen's d = 0.65) induced by local BM cues (Yu et al., 2020) showed that at least 21 participants would be needed to afford 80% power. Therefore the sample size was further expanded to 24 per experiment (Experiments 4–6) to detect the effect of local BM cues.

Stimuli

Stimuli were generated and displayed using MATLAB (Mathworks, Inc., Natick, MA, USA) together with the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). Point-light human BM stimuli with leftward or rightward walking direction were adopted from Vanrie and Verfaillie (2004). In addition, a point-light walker displayed in frontal view was used as the neutral cue. In Experiment 1, the BM sequence was depicted by 13 white dots, which represented the motions of a walker's head and major joints (shoulders, elbows, wrists, hips, knees, and ankles). Each gait cycle was 1 s and contained 30 frames. In order to avoid participants' prediction, the initial frame of the point-light display was randomized in each trial. In Experiment 2, everything was the same as in Experiment 1 except that the point-light walker was mirror flipped vertically. In Experiment 3, critical biological characteristics of the BM stimuli were removed, which served as non-BM sequences. Specifically, each individual dot of non-BM stimuli moved along a path identical to that of the BM stimuli but with a constant speed equal to the average speed of the corresponding BM dot. And the initial motion phase of each individual dot was also randomized. Such manipulations disrupted the natural velocity profile and phase relationship of the BM stimuli but kept other motion properties of individual dots unchanged (Dayan et al., 2007; Y. Wang et al., 2018; Yu et al., 2020). Motion sequences in Experiments 1–3 subtended approximately 2.8° × 6.6° in visual angle. In Experiment 4, the feet motion sequences, created by isolating the two point lights of ankles from the original BM sequences with leftward or rightward walking direction, served as local BM cues. They consisted of two fragments that represented the stance

phase and swing phase of the foot trajectory. During the stance phase, the corresponding dot moves in the opposite direction of the walking direction at an approximately constant velocity. During the swing phase, the dot accelerates along both the horizontal and the vertical dimensions due to muscle activity and gravitational acceleration. It should be noted that the feet motion sequences retain local motion information only but are devoid of global configuration information that is contained in the intact BM sequences. The feet motion sequences were vertically mirror flipped in Experiment 5, which disrupted the intrinsic biological information (e.g., vertical acceleration due to muscle activity and gravity), whereas the horizontal, translatory motion in the stance phase remained unchanged. Each local BM sequence in Experiments 4 and 5 was about 2.8º × 0.5º in visual angle. In Experiment 6, the inanimate motion cue was a dot shifting 0.5º directly to the left or right of the center fixation, which produced the illusion of apparent motion. In all experiments, the memory items were colored squares (0.7º × 0.7º) randomly sampled from a set of eight colors (red, orange, yellow, green, cyan, blue, purple, and pink). All stimuli were presented against a gray background and the viewing distance was about 60 cm.

Procedure

Participants completed a color change detection task with a pre-cueing manipulation (Fig. 1). At the beginning of each experiment, participants were explicitly told that all cues would not predict the location of memory arrays and were required to fixate at the central cross throughout the experiment. In Experiment 1, each trial began with fixation on a central cross (0.35º × 0.35º). After 1,000 ms, a BM cue appeared at the center of the screen. After a stimulus-onset asynchrony (SOA) of 500 ms, colored squares were presented for 200 ms on the left or right side of the BM cue, which remained onscreen. Participants had to memorize the squares for a recognition test at the end of trial. The squares, configured in memory arrays of four (set size 4) or six (set size 6), were arranged on one side of an invisible circle with a radius of 7º centered on the middle of the screen. It was followed by a 1,000-ms WM maintenance interval and then a single square probe was presented in the center of the screen. Participants were asked to judge whether this square had been presented in the memory array via a key press within 3,000 ms. There was a 50% probability that the square probe was new. Feedback was given to participants after every trial. Experiments 2 and 3 followed the same design and procedure as in Experiment 1, except that the BM sequences were shown inverted (Experiment 2) or changed to non-BM sequences (Experiment 3). Note that the motion properties of non-BM sequences (e.g., average speed) were matched with that of BM sequences (see *Stimuli* for more detail). Experiment 4 was similar in procedure to Experiment 1, but the feet motion sequences with leftward or rightward walking direction instead of the intact BM sequences were used as the central cue, and the set size was four only. Experiment 5 was consistent with Experiment 4, with the only difference being that the feet motion sequences were inverted. It should be pointed out that the inverted feet
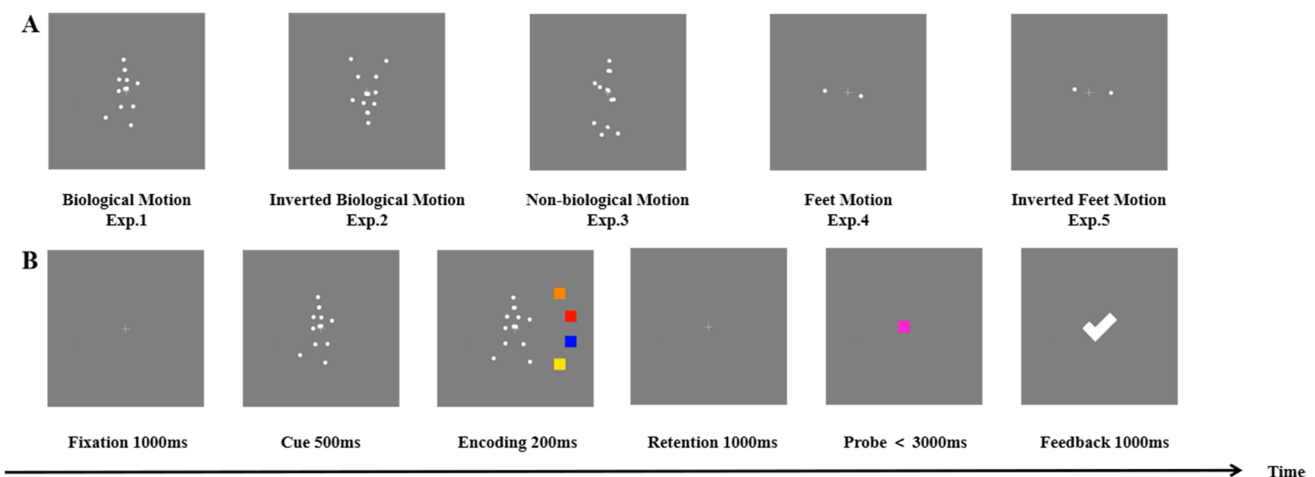

Fig. 1 Schematic representation of the experimental paradigm. (**A**) Different types of cues in each experiment. (**B**) Each trial started with a 1,000-ms fixation, followed by a central cue for 500 ms. With the cue remaining onscreen, the colored squares were presented for 200 ms on either the left or right side of the cue. Participants were required to remember the presented colors. After a 1,000-ms working memory (WM) maintenance interval, a single square probe was presented in the center of the screen. Participants were asked to judge whether this square had been presented in the memory array via a key press as quickly as possible while minimizing errors within 3,000 ms. Feedback was given to participants after every trial. At the beginning of each experiment, participants were explicitly told that the cue was not predictive of target location

motion cues could induce a significant but reverse attentional effect, resulting in a facilitated performance in the incongruent condition compared to the congruent condition (Wang et al., 2014; Yu et al., 2020). This reverse attentional effect seems to arise from the translatory (extrinsic) motion in the stance phase (see *Stimuli* for more detail) that essentially points to the opposite direction of the walking direction. Experiment 6 began with a 1,000-ms fixation, followed by a dot cue displayed at the center of the screen for 750 ms. The dot cue then shifted 0.5° horizontally to either the left or right and remained on the screen for an additional 100 ms (SOA). Subsequently, memory items were presented for 200 ms in either the left or the right side of the fixation. The following procedure remained the same as that of Experiment 1. The SOA was shortened to 100 ms to avoid the potential inhibition-of-return (IOR) effect (R. M. Klein, 2000; Samuel & Kat, 2003; Taylor & Klein, 1998; Wang et al., 2017).

In Experiments 1–3, there were 288 trials in total for each participant and for each experiment, with half of trials for set sizes of 4 and 6, respectively. The two set-size conditions were run in separate blocks and the order was counter-balanced across subjects. Each set-size condition consisted of 144 trials with 48 congruent trials (the location of memory arrays was the same as the cued direction), 48 incongruent trials (the location was opposite to the cued direction), and 48 neutral trials (neither side was cued). In Experiments 4–6, participants completed 96 trials consisting of 48 congruent trials and 48 incongruent trials with a set size of 4.

In order to confirm that the inanimate low-level motion cue (i.e., dot motion) could also induce an attentional orienting effect, all participants in Experiment 6 completed an additional task using the traditional target location discrimination paradigm before the formal experiment. In this task, a dot cue was first presented at fixation for 750 ms, and then shifted 0.5° horizontally to the left or right for 100 ms (SOA), which was the same as the formal experiment. After that, a Gabor patch (1.2° × 1.2°) appeared in either the congruent or the incongruent location as a target, and the horizontal distance between the centers of the Gabor patch and the fixation was 7°. Participants were required to indicate the location of the target via a key press as quickly as possible while giving priority to response accuracy. The motion cue was irrelevant to the task and not predictive of target location. There were 80 trials in total with 40 congruent trials and 40 incongruent trials.

Data analysis

In all experiments, trials with reaction times (RTs) less than 100 ms or greater than 3,000 ms were excluded from the statistical analysis (0.23% of all trials). The performance of the task was calculated according to the signal detection theory, in which the detection sensitivity (d') and the response criterion (β) were assessed based on hit and false alarm rates (Macmillan & Creelman, 2005). In Experiments 1–3, a 2 (set size: 4 or 6) × 3 (congruency: congruent, incongruent or neutral) repeated-measures ANOVA was used to analyze d' and β separately. In Experiments 4–6, a paired t-test was conducted with the factor of congruency (congruent vs. incongruent). Greenhouse-Geisser correction was used when the spherical assumption was violated.

Results

When BM sequences were presented as central cues in Experiment 1, the results showed a significant main effect of set size for d', $F(1,15) = 43.77$, $p < .001$, $\eta_p^2 = .75$, but the main effect of congruency was not significant, $F(2,30) = 1.23$, $p = .308$, $\eta_p^2 = .08$. More importantly, there was a significant interaction between set size and congruency, $F(2,30) = 3.97$, $p = .029$, $\eta_p^2 = .21$. A simple effect analysis for d' was carried out to test the significant interaction. When the set size was 4, WM performance in the congruent condition ($M = 1.62$, $SD = 0.53$) was significantly better than that in the incongruent condition ($M = 1.26$, $SD = 0.74$), $t(15) = 2.36$, $p = .032$, Cohen's $d = 0.59$, 95% confidence interval (CI) for the mean difference [0.03, 0.67], and the difference between the congruent and the neutral conditions ($M = 1.32$, $SD = 0.59$) was marginally significant, $t(15) = 1.94$, $p = .072$, Cohen's $d = 0.49$, 95% CI for the mean difference [-0.03, 0.62] (Fig. 2A). No significant difference was found between the incongruent and the neutral conditions, $t(15) = -0.63$, $p = .540$, Cohen's $d = 0.16$, 95% CI for the mean difference [-0.25, 0.14]. The results indicated that non-predictive BM cues improved WM and increased the likelihood of remembering items presented at the location cued by walking direction of BM when the set size was 4. This effect appeared to be driven by enhanced engagement rather than delayed disengagement, which is consistent with previous studies (Friesen & Kingstone, 1998; Gregory & Jackson, 2017). The observed modulation effect was not due to a difference in the response criterion, since participants' β values were not significantly different between the congruent condition ($M = 1.68$, $SD = 1.18$) and the incongruent condition ($M = 1.37$, $SD = 0.89$) when the set size was 4, $t(15) = 1.34$, $p = .199$, Cohen's $d = 0.34$, 95% CI for the mean difference [-0.18, 0.81]. When the set size was 6, d' for the congruent condition ($M = 0.69$, $SD = 0.53$) did not significantly differ from that for the incongruent condition ($M = 0.74$, $SD = 0.44$), $t(15) = -0.31$, $p = .759$, Cohen's $d = 0.08$, 95% CI for the mean difference [-0.35, 0.26]. No significant difference was found between the congruent and the neutral conditions ($M = 0.89$, $SD = 0.48$), or between the incongruent and the neutral conditions, $ps > .1$. Furthermore, there was no significant difference observed for β
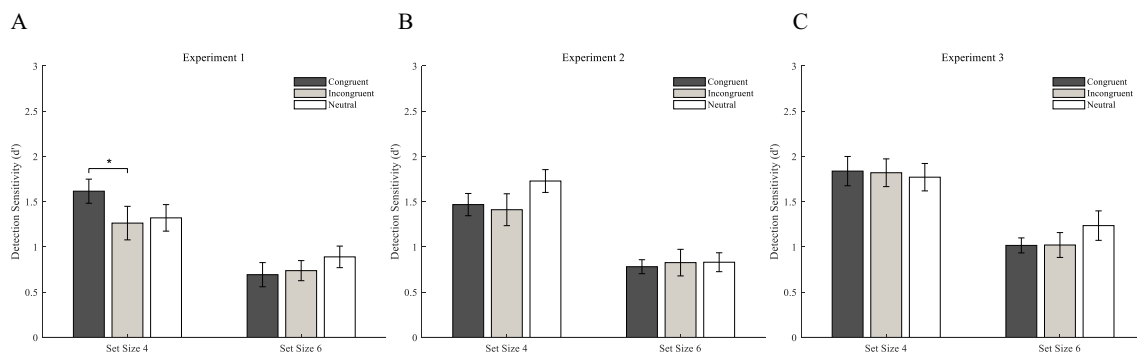
Fig. 2 Results from Experiments 1–3. (**A**) When biological motion (BM) sequences were presented as central cues (Experiment 1), working memory (WM) performance in the congruent condition was significantly more accurate than that in the incongruent condition only with a set size of 4. (**B**, **C**) No significant difference was observed when the BM stimuli were mirror flipped vertically (Experiment 2), or when critical biological characteristics of the BM stimuli were removed (Experiment 3). Error bars show standard errors. *$p < .05$

(congruent: $M = 1.19$, $SD = 0.41$; incongruent: $M = 1.17$, $SD = 0.33$; neutral: $M = 1.27$, $SD = 0.53$), $ps > .1$. Taken together, these results implied that the observed modulation effect might be influenced by task difficulty or resource demands (Lavie et al., 2004).

When the BM cues were mirror flipped vertically in Experiment 2, the main effect of set size for d' was significant, $F(1,15) = 29.77$, $p < .001$, $\eta_p^2 = .67$, while the main effect of congruency was not significant, $F(2,30) = 1.45$, $p = .250$, $\eta_p^2 = .09$, which were similar to the results obtained in Experiment 1. Conversely, no significant interaction effect of set size and congruency was found, $F(2,30) = 1.25$, $p = .301$, $\eta_p^2 = .08$ (Fig. 2B). These results showed that the observed modulation effect vanished when the BM cues were shown inverted, suggesting that this effect did not arise from the processing of low-level features.

In order to examine whether the observed modulation effect was indeed triggered by the biological characteristics of the BM signals, we conducted another control experiment (Experiment 3) in which non-BM sequences were adopted as central cues. Results showed that the main effect of set size for d' was significant, $F(1,15) = 55.34$, $p < .001$, $\eta_p^2 = .79$, while the main effect of congruency was not significant, $F(2,30) = 0.40$, $p = .674$, $\eta_p^2 = .03$, and there was no significant interaction between set size and congruency, $F(2,30) = 1.42$, $p = .258$, $\eta_p^2 = .09$ (Fig. 2C). These findings suggest that the modulation effect on WM was essentially triggered by the biological characteristics contained in the motion signals.

To further investigate whether the observed modulation effect could be induced by local BM signals that were deprived of global configuration, we adopted feet motion sequences in Experiment 4. Results showed that WM performance in the congruent condition ($M = 1.63$, $SD = 0.55$) was significantly more accurate than that in the incongruent condition ($M = 1.33$, $SD = 0.57$), $t(23) = 2.59$, $p = .016$,

Cohen's $d = 0.53$, 95% CI for the mean difference [0.06, 0.54], suggesting that local BM cues without global configuration could still influence WM performance (Fig. 3). This significant effect of congruency for d' could not be attributed to a difference in the response criterion either, as the β under the congruent condition ($M = 1.42$, $SD = 1.52$) was not different from that under the incongruent condition ($M = 0.98$, $SD = 0.33$), $t(15) = 1.55$, $p = .136$, Cohen's $d = 0.32$, 95% CI for the mean difference [-0.15, 1.03]. The magnitude of the modulation effect (calculated as the difference in mean d' obtained under the incongruent condition vs. that under the congruent condition divided by their sum, $\frac{d'_{\text{incongruent}} - d'_{\text{congruent}}}{d'_{\text{incongruent}} + d'_{\text{congruent}}}$)
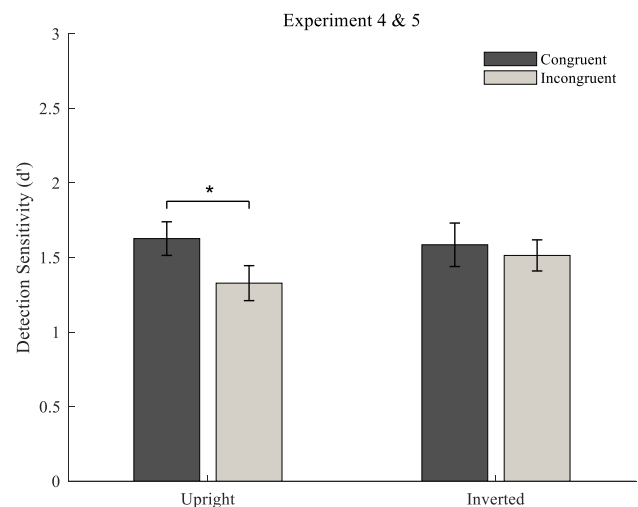

Fig. 3 Results from Experiments 4 and 5. When feet motion sequences were presented as central cues (Experiment 4), working memory performance in the congruent condition was significantly more accurate than that in the incongruent condition. This effect vanished when stimuli were mirror flipped vertically in Experiment 5. Error bars show standard errors. *$p < .05$

induced by feet motion cues was not different from that induced by intact BM cues when the set size was 4, $t(38)$ = -0.60, p = .552, Cohen's d = 0.19, 95% CI for the mean difference [-0.19, 0.11]. These results indicated that the modulation effect on WM did not necessarily depend on global configuration and could be triggered by local motion signals alone. However, no significant difference was found when the feet motion cues were mirror flipped vertically in Experiment 5 (congruent: M = 1.59, SD = 0.71; incongruent: M = 1.51, SD = 0.51), $t(23)$ = 0.54, p = .595, Cohen's d = 0.11, 95% CI for the mean difference [-0.20, 0.34], suggesting that the observed modulation effect critically depended on upright but not inverted local BM signals. Combined with the evidence that inverted feet motion can also induce attentional effects (see *Methods* for more detail), our finding here indicated that the observed modulation effect was highly tuned to BM but not to inanimate motion signals.

In Experiment 6, we employed another inanimate motion cue to further verify that the observed modulation effect on WM was specifically induced by biological motion signals. The traditional target location discrimination task conducted before the formal experiment showed that the dot motion cue could reliably orient attention to a laterally presented Gabor patch (congruent: M_{RT} = 404.30 ms, SD = 91.81 ms; incongruent: M_{RT} = 428.07 ms, SD = 87.79 ms), $t(23)$ = -5.97, p < .001, Cohen's d = 1.22, 95% CI for the mean difference [-32.00, -15.54], consistent with previous studies (Gregory & Jackson, 2017; Tipples, 2002, 2008). However, the modulation effect was not found in the WM task (congruent: M = 1.70, SD = 0.55; incongruent: M = 1.83, SD = 0.59), $t(23)$ = -1.00, p = .329, Cohen's d = 0.20, 95% CI for the mean difference [-0.39, 0.14]. Overall, these findings together with Experiments 4 and 5 demonstrated that local BM cues improved WM performance, while inanimate motion cues (i.e., inverted feet motion and dot motion) did not, despite all of them being able to direct attention.

Discussion

The walking direction of biological entities can induce a fast and robust reflexive attentional orienting effect, a phenomenon known as social attention (Klein et al., 2009; Nummenmaa & Calder, 2009; Shi et al., 2010). In the current study, we demonstrated that such a fundamental ability could further affect higher-level cognitive processes. Specifically, BM sequences as pre-cues modulated the encoding process and improved WM performance. This improvement disappeared when the BM cues were shown upside-down, which reflected an inversion effect in BM processing (Chang & Troje, 2009; Troje & Westhoff, 2006; Vallortigara & Regolin, 2006). This effect also vanished when critical biological characteristics of the BM stimuli were removed, although

the moving trajectories and average speed of each dot remained the same. Moreover, local BM cues, consisting of only the two point lights of the ankles without global configuration, still significantly influenced WM performance. In contrast, inanimate motion cues such as inverted feet motion and dot motion had no significant impact on WM, although they also elicited attentional effects. These findings together demonstrate that the biological characteristics embedded in the motion signals independent of global configuration can modulate visual WM, with the effect specific to life motion signals rather than inanimate motion cues.

A similar modulation effect on WM was observed with another social cue by prior researchers (Gregory & Jackson, 2017). They adopted eye gaze as a non-predictive central cue and found that the gaze-induced social attention modulated WM significantly. It has been demonstrated that both eye gaze and BM stimuli can trigger an analogous social attention effect (Friesen & Kingstone, 1998; Langton et al., 2000; Shi et al., 2010; Yuan et al., 2022), and they share common genetic and neural mechanisms, implying the existence of a "social attention detector" in the human brain (Ji et al., 2020; Wang et al., 2020). Based on these observations, the similar modulation effects of BM and eye gaze on WM process suggest a general and shared "social attention detector" from a high-level cognitive function perspective. Furthermore, our study provides new evidence on the long-standing debate regarding whether or not social attention is distinct from non-social attention (Friesen et al., 2004; Ji et al., 2022; Joseph et al., 2015; Sato et al., 2010; Tipples, 2002, 2008). Our study demonstrated that BM signals specifically induced a modulation effect on WM, which was not found with non-social cues. Moreover, no modulation effect on WM was observed when the uninformative non-social cue (i.e., arrow) was adopted in the previous study (Gregory & Jackson, 2017), paralleling our findings obtained with inverted feet motion cues and dot motion cues. From the above-mentioned evidence, we can infer that the processing of social cues may be distinct from that of non-social cues. Despite the fact that both social and non-social cues can elicit attentional orienting, they exert differentiated effects on higher-level cognitive processes. Altogether, our study shed new light on the distinctiveness of social attention in high-level cognitive functions.

Findings of the current study also further our understanding of the relationship between attention and WM. Attention is closely related to WM, and the effect of attention on WM has been widely discussed (Baddeley, 1993; Kane et al., 2001; Oberauer, 2009). Previous studies suggest that allocating attention to a location before stimulus onset enhances the detection and processing of cued items, facilitating their encoding into WM (Carrasco et al., 2004; Pestilli & Carrasco, 2005). While non-social cues have been shown to improve memorization of targets displayed at cued locations,

they are typically predictive (Griffin & Nobre, 2003; Li & Saiki, 2015; Tanoue et al., 2013). It may involve top-down control of attention, which contributes to encoding and maintaining items in WM (Gazzaley & Nobre, 2012; Jacob et al., 2015). However, in our study, the BM cues were not predictive, and participants were informed of this before the experiments, ruling out top-down attentional control as a factor in the observed modulation effects on WM. Notably, BM-mediated orienting represents a new form of spatial attention and is distinct from traditionally identified types of covert attention (i.e., exogenous and endogenous) (Ji et al., 2020; Liu et al., 2021; Wang et al., 2020). The fundamental social attention ability allows humans to gain insight into the inner state of others and identify important events in their environment (Nummenmaa & Calder, 2009). The present study, for the first time, showed that this unique social attention induced by BM cues could specifically contribute to the processing and encoding of information into WM, offering new insight into the interactions between attention and WM.

It is worth noting that the modulation effect on WM could be extended to local BM stimuli without any global configuration, which parallels previous findings on the perception of local BM cues (Troje & Westhoff, 2006; Wang et al., 2010; Wang & Jiang, 2012). The motion of the feet in BM walking direction perception has been highlighted by some researchers as playing a distinctive role (Chang & Troje, 2009; Cheng et al., 2022; Gurnsey et al., 2010; Johnson, 2006; Saunders et al., 2009). It has been demonstrated that feet motion cues can not only be processed independent of global configuration, but also induce robust reflexive attentional orienting even without observers' subjective awareness of their biological nature (Wang et al., 2014). Therefore, it has been proposed that there might exist an intrinsic brain mechanism specialized to life motion signals, which is sensitive to the direction of the limbs of another moving creature (i.e., life motion detector) (Cheng et al., 2023; Ma et al., 2022; Troje & Westhoff, 2006; Wang et al., 2010, 2014; Wang & Jiang, 2012; Wang et al., 2018, 2022; Yu et al., 2020). In the present study, we examined the processing of feet motion cues by combining a WM task, and found that local BM stimuli could modulate WM performance. Our findings extended prior social attention studies and further demonstrated that "life motion detector" could also play a special role in higher-level cognitive processes (i.e., WM). In addition to BM, from a more comprehensive view, there are several other animate motion signals, such as self-propelled motion, change of speed, and unpredictability of motion (Di Giorgio et al., 2021; Lemaire et al., 2022; Lorenzi et al., 2017; Rosa-Salva et al., 2016; Vallortigara & Losi, 2021). Future studies can adopt these animate signals to further explore whether they can operate in higher-order cognitive processes.

In summary, the current study demonstrates that non-predictive BM signals independent of global configuration can modulate WM performance and improve memory of items presented at the BM-cued location. However, such modulation effect cannot be observed with inanimate motion cues (i.e., inverted feet motion and dot motion). These findings together support for the existence of a "life motion detector" in the human brain, and suggest that the specialized attention mechanism tuned to life motion signals can penetrate to higher cognitive processes.

Declarations

Conflict of interest None.

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