



Original Articles

Biphasic attentional orienting triggered by invisible social signals

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ABSTRACT

Biological motion (BM) is one of the most important social cues for detecting conspecifics, prey, and predators. We show that unconscious BM processing can reflexively direct spatial attention, and that this effect has a biphasic temporal profile. Participants responded to probes that were preceded by intact or scrambled BM cues rendered invisible through continuous flash suppression. With a short inter-stimulus interval (ISI, 100 ms) between the invisible BM cues and the probe, responses to probes at the same location as the invisible, nonpredictive BM cue were faster than to probes at the location of the scrambled BM cue. With a longer ISI (800 ms) this effect reversed, with slower responses to probes at the location of the invisible, nonpredictive BM. These effects were absent when BM and its scrambled control were made visible with both short and long cue durations across variable length of ISIs, indicating that the saliency of BM itself cannot account for the dynamic orienting effects from invisible social cues. Moreover, this dynamic attentional shifts were specific to upright BM cues and not obtained for inverted stimuli. Thus, this reflexive and dynamic attentional modulation triggered by invisible BM, with initial facilitation followed by inhibition, demonstrates that in the complete absence of conscious awareness, cue predictiveness, and saliency differences, attentional systems promote exploration of our visual environment for social signals.

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1. Introduction

Biological motion (BM), which broadly refers to the movements of animate entities (Johansson, 1973; Troje, 2013), is a social signal that carries information critical for survival and interpersonal interactions. BM can be detected quickly and automatically by the visual system. Many studies have demonstrated that human observers are highly adept at detecting and interpreting BM signals, even when they are portrayed via a simple set of tiny light points (e.g., 12 points) placed at distinct joints of a moving agent (Johansson, 1973). Although highly impoverished (e.g., without texture and form cues), once in motion, these point-light displays (PLDs) are rapidly recognized as coherent, meaningful movements. Moreover, multiple aspects of social information, such as walking direction, gender, interactions, and emotion, can be readily

perceived, even if the PLDs are presented within dynamic noise (for reviews, see Blakemore, 2008, 2012; Puce & Perrett, 2003; Steel, Ellem, & Baxter, 2015; Troje, 2013). Such findings have led to the notion that BM can be processed automatically, requiring little attentional resources (see Thompson & Parasuraman, 2012, for a review; Thornton & Vuong, 2004). One intriguing possibility is that the processing of BM does not even require conscious awareness. Indeed, recent evidence suggests that even when rendered invisible, some low-level aspects of BM continue to be accessed at relatively early stage of visual processing (Favre & Koch, 2014).

One challenge for studying unconscious BM processing consists in rendering BM stimuli invisible. Standard psychophysical techniques such as backward masking require stimuli to be presented very briefly, and therefore do not allow for sufficient presentation time for a temporal sequence necessary for BM. This issue can be circumvented by using continuous flash suppression (CFS), a particularly potent interocular suppression technique in which a stimulus presented to one eye can be rendered fully invisible for several seconds by dynamic, high-contrast masks flashed onto the other eye (Tsuchiya & Koch, 2005). With this CFS technique it is possible to study unconscious processing of stimuli that require longer presentation durations, such as motion and BM (Favre & Koch, 2014;

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Maruya, Watanabe, & Watanabe, 2008). CFS has been used to demonstrate that, in addition to low-level stimulus properties (e.g., Hong & Blake, 2009; Maehara, Huang, & Hess, 2009; Tsuchiya & Koch, 2005), also some high-level biological and social information can be processed without awareness. For example, upright faces break through CFS faster than do inverted faces (Jiang, Costello, & He, 2007). Although this breaking CFS paradigm (b-CFS; Jiang et al., 2007; Stein, Hebart, & Sterzer, 2011) may not provide unequivocal evidence for unconscious visual processing (Stein & Sterzer, 2014), the advantage of upright faces in gaining access to awareness suggests that the upright facial configuration is extracted before awareness of the face. Recently, Stein, Sterzer, and Peelen (2012) extended these findings by showing that upright human bodies break CFS faster than inverted bodies, indicating that perceptual processing under CFS is tuned to visual signals diagnostic of other human beings.

What could be the functional significance of such preferential unconscious processing of biologically and socially relevant visual signals? One possibility is that unconscious processing guides visual attention to those stimuli in the environment that are particularly important for survival and social interaction, without involving capacity-limited, metabolically costly conscious awareness (Dehaene & Changeux, 2011). Indeed, Jiang, Costello, Fang, Huang, and He (2006) provided initial evidence for this idea, using sexually arousing stimuli. This study used an unconscious variant of the Posner cuing paradigm, in which attention is attracted exogenously by a physically salient cue flashed in a peripheral probe location (Posner & Cohen, 1984) to investigate whether unconscious, nonpredictive (cue validity: 50%) stimuli can attract attention. The results from Jiang et al. (2006) demonstrated that fully invisible erotic images reflexively attracted spatial attention, in contrast to predictive (cue validity: around 70% or higher), exogenous cues defined by physical salience, such as abrupt onsets. However, it is possible that such unconscious attentional cuing is restricted to sexually arousing stimuli, and it is thus unknown whether similar effects exist for sexually neutral stimuli of outstanding biological and social significance, such as BM. While there is some evidence for the extraction of gender information from invisible BM (Faivre & Koch, 2014), to the best of our knowledge, it has not been tested whether invisible BM can induce reflexive attentional shift.

Recent work shows that visible BM walkers can reflexively and robustly direct spatial attention in their walking direction. This attentional orienting effect from visible BM was first shown by Shi, Weng, He, and Jiang (2010). In their study, following a brief display (i.e., 500 ms) of BM (as a central cue) walking either to the left or to the right, observers' performance in a subsequent probe discrimination task was better when the probe was presented in the walking direction than in the opposite direction even when observers were explicitly aware that walking direction was not predictive of probe location (Shi et al., 2010). This attentional orienting effect from BM is similar to classic results from the literature on attentional orienting from gaze directions (Friesen & Kingstone, 1998; Langton, Watt, & Bruce, 2000). Thus, like gaze direction, BM represents an important social cue that can induce reflexive shifts of attention.

In the present study, we used an unconscious variant of the Posner cuing paradigm, similar to Jiang et al., 2006, to investigate whether invisible BM can reflexively attract spatial attention. A meaningful, intact BM cue and its scrambled control were presented in different spatial locations to the non-dominant eye and were rendered invisible by novel, custom-built CFS masks (Fig. 1, see also Tsuchiya & Koch, 2005) to the dominant eye. To assess whether unconscious social signals can modulate spatial attention and whether this influence has a specific temporal profile, probes followed the cues with varying inter-stimulus intervals (ISIs). With

visible, exogenous cues, the Posner cuing paradigm yields a classic biphasic pattern of facilitation and inhibition: For short ISIs (e.g., 100 ms) reaction times (RTs) are faster to probes at the cued location than at the non-cued location (facilitation), but slower for longer ISIs (e.g., 800 ms, inhibition of return [IOR]). IOR is often described as a 'foraging facilitator', because it facilitates visual search by preventing attention from returning to previously attended locations before exploring other parts of the visual field (Klein, 2000). There is some evidence that IOR can be observed with subliminal, predictive (i.e., cue validity around 70% or above) spatial cues (Mulckhuyse & Theeuwes, 2010), but there has been no investigation on biphasic attentional effects from invisible, non-predictive (i.e., cue validity: 50%) social stimuli such as biological motion.

2. General method

2.1. Participants

Twenty observers (16 female, age range: 19–30 years, mean age: 21 years) participated in Experiment 1a, and a new group of twenty observers (13 female, age range: 19–30 years, mean age: 21 years) participated in Experiment 1b. Another new group of twenty observers (17 female, age range: 19–30 years, mean age: 21 years) participated in Experiment 2a, and an additional group of twenty observers (16 female, age range: 19–22 years, mean age: 20 years) participated in Experiment 2b. Participants were recruited from Shandong Normal University, and all had normal or corrected-to-normal vision. Participants were naïve to the purpose of the study and provided written consent prior to the participation. The study was approved by the Research Ethics Board of Shandong Normal University.

Twenty students from Zhejiang University (9 female, age range: 18–22 years, mean age: 19 years) were paid to participate in the Experiment 3 and signed consent forms. The study was approved by the Research Ethics Board of Zhejiang University.

To ensure adequate power, the sample size was determined by a power analysis based on predicted effect size using *G*power* 3 (Faul, Erdfelder, Buchner, & Lang, 2009). Based on the results of previous studies (Jiang et al., 2006; Xu, Zhang, & Geng, 2011), we predicted a large effect size ($d = 0.65$, according to Cohen, 1988) for our experimental design. With 80% power at the 0.05 significance level, the suggested sample size was approximately 20 individuals. The sample sizes for all experiments reported here were determined by the same rule.

2.2. Apparatus and stimuli

Visual stimuli were generated on a PC computer using Psychopy (Peirce, 2007), and presented on a linearized CRT monitor (21" Sony G520; resolution: 1024 × 768 pixels; refresh rate: 100 Hz). Participants viewed the screen from a distance of 70 cm in a dark room. Binocular fusion frames (10.9° × 5.45° for Experiments 1a, 1b, 2a, and 2b) surrounding the stimuli were always presented to promote stable binocular eye alignment. Stimuli were viewed through a mirror stereoscope and presented against a uniform gray background at mean luminance (17.5 cd/m²).

Five BM stimuli (crawl, jump, row, walk, and wave) were selected from the Vanrie and Verfaillie (2004) database. Each original BM sequence comprised 13 dots depicting the movement of the head and the major joints (shoulders, elbows, wrists, hips, knees, and ankles). Pair-wise shuffled motion (PSM) variants of these BM stimuli (for Experiments 1a, 2a, 2b, and 3) and inverted BM stimuli (for Experiment 1b) were used as foils. PSM stimuli are improved scrambled controls in which relations among local

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