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Spatial distortion induced by imperceptible visual stimuli

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ABSTRACT

Previous studies have explored the effects of attention on spatial representation. Specifically, in the attentional repulsion effect, a transient visual cue that captures attention has been shown to alter the perceived position of a target stimulus to the direction away from the cue. The effect is also susceptible to retrospective influence, that attention appears to attract the target when the cue appears afterwards. This study examined the necessity of visual awareness of the cue in these phenomena. We found that when the cues were rendered invisible by backward visual masks, both repulsion and attraction effects were weakened but still observed. The results suggest that the effects possibly depend on processes that are not necessarily associated with conscious visual awareness of the cues. We conjecture that attentional shift produced by the weak, invisible cues may play a role in spatial distortion; but other possible accounts including non-attentional ones are also discussed.

1. Introduction

The environment with which humans interact is enormously rich in sensory information. However, due to limits in its processing capacity, the human perceptual/cognitive system selectively processes the information that is most relevant to the current tasks or to survival. Attention has long been considered to be a filter that selects incoming sensory information (Broadbent, 1958) by enhancing information processing at a focused location while suppressing it at other locations. Besides voluntary focusing of attention, the sudden onset of a peripheral cue can cause one to reflexively shift attention to the cue's location, which has been shown to facilitate faster and more accurate responses to targets appearing at the cued location (Posner, 1980; Posner & Cohen, 1984).

In addition to selecting and filtering incoming information, attention has been shown to alter perception. Carrasco, Ling, and Read (2004) showed that attention induced by a brief cue led to perception of higher contrast. Alternation of stimulus appearance by attention has also been demonstrated in different dimensions of visual properties, including spatial frequency and gap size (Gobell & Carrasco, 2005), color saturation (Fuller & Carrasco, 2006), motion coherence of dots (Liu, Fuller, & Carrasco, 2006), size of moving patterns (Anton-Erxleben, Henrich, & Treue, 2007), and speed of moving objects (Turatto, Viscovi, & Valsecchi, 2007).

Attention also modifies spatial and temporal representations. The line-motion illusion (Hikosaka, Miyauchi, & Shimojo, 1993) demonstrates the effect of orienting one's attention (by sudden appearance of stimulus) on temporal perception. When preceded by the brief presentation of a location cue, a line presented physically at once is perceived as propagating

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away from the side of the cue towards the opposite side. Hikosaka et al. (1993) considered that the facilitatory effect of attention peaks at the cued location and decreases in a gradient as the distance from the cued location increases. They proposed that visual input from locations nearer to the cue reached the central nervous system's motion detector at an earlier moment, followed by the input from adjacent positions, and so on, resulting in the illusion of motion.

Besides eliciting temporal influence, a brief and sudden presentation of stimulus can distort spatial representation as well. In a study by Suzuki and Cavanagh (1997), observers viewed flashed cue stimuli, which consisted of one circle located in one of the quadrants of the screen or two circles arranged diagonally in opposite pairs of quadrants, followed by a vernier target stimulus constructed with a pair of vertical bars displayed above and below the center of the screen after varied stimulus onset asynchrony (SOA – presentation interval between the onset of the cue and that of the target). Their results indicated that observers perceived the targets as displaced away from the location of cue stimuli. They called this the "attentional repulsion effect" and suggested that the effect was due to the costs of resource allocation to the focus of attention. Using tasks with stronger action components (a computer mouse localization task and a guided limb localization task), the attentional repulsion effect has been found to affect both perception and action (Pratt & Turk-Browne, 2003).

Eye movements are intimately linked with attention. In parallel to the effect of attention on eliciting spatial and temporal distortion, there is also a large body of research reporting the effects of saccadic eye movements on distorting spatial and temporal representation (Morrone, Ross, & Burr, 2005; Ross, Morrone, Goldberg, & Burr, 2001). Compression of visual space has been observed before saccades (Lappe, Awater, & Krekelberg, 2000; Ross, Morrone, & Burr, 1997), and differential perceptual localization has been observed at the beginning and at the end of a saccade (Honda, 1989) and also during real and simulated saccadic eye movements (Morrone, Ross, & Burr, 1997). However, since the observers fixated firmly during the task performance in the experiments of the present study, in this paper we confine our discussion on attentional influence on spatial localization under the situation without eye movements.

Attentional shift is not always accompanied by conscious awareness of cues. In parallel with stimuli that the observer is consciously aware of, the dynamic deployment of visual attention has been observed for visual stimuli that are masked and consequently go unnoticed (Mulckhuyse, Talsma, & Theeuwes, 2007). In that study, after a very brief positional cue was displayed, mask stimuli were presented at all possible target locations in order to make the cue invisible. The response detection time was shorter at the cued than at the uncued location in the short-SOA condition; this effect was reversed when SOA was longer (inhibition of return [Klein, 2000; Posner & Cohen, 1984]). In addition, Blanco and Soto (2009) reported that the line-motion illusion did not depend on conscious awareness of the flashed cue because it occurred even when the cue was rendered invisible by the presentation of a mask. This technique of masking a very briefly presented cue to suppress the visibility of the stimuli (backward masking) has also been applied to the study of object-based attention: Chou and Yeh (2011) examined whether a subliminal positional cue followed by a mask would affect the reaction time for identifying the position of the target. A subliminal cue facilitated a different-object advantage in locating the target, whereas a supraliminal cue facilitated a same-object advantage.

If cues presented below observer's visual awareness could unconsciously draw the observer's attention, do invisible stimuli influence the observer's spatial representation? More specifically, would invisible cues induce the attentional repulsion effect? These questions constituted one of the two core motivations of the present study; that is, to elucidate the role of visual awareness in the attentional modulation of spatial representation. Given their broadness, it would be difficult to clearly delineate the concepts of attention and visual awareness and provide comprehensive definitions for each term. However, in the present paper we simply define that visual awareness describes the situation where the observer is able to consciously report; and attention is exogenously captured by the sudden appearance of the positional cue in our present experiment, which leads to differential processing engaged by the visual system on the "attended" (facilitated) and "unattended" (non-facilitated) positions (some examples were explained in Posner and colleagues as mentioned above). They can obviously interact with each other but they do not always co-exist (Koch & Tsuchiya, 2007; Lamme, 2003).

The other motivation of the present study was related to the temporal relationship between attentional cues and visual stimuli that are to be affected by attentional shift. Recently, there has been increasing interest in studying the attentional influence of events occurring after a target event. In their discussion of the flash-lag phenomenon, Eagleman and Sejnowski (2000) argued that visual awareness is a postdictive process; events occurring after the disappearance of visual stimulus can influence the visual system's interpretation, and its processing is delayed for a brief window of time to settle on the best interpretation of the scene. Based on this hypothesis, they found that the line-motion illusion could in fact be reversed by signals occurring after the disappearance of the cue and target line (Eagleman & Sejnowski, 2003). These authors suggested the possibility that the attentional processing of the cue generated an initial motion signal around its position, which was then integrated with the opposing signal of the dot displacement. The resultant motion signal within this time window was later applied to the line, producing the effect of movement in the opposite direction as a consequence. A similar reversal phenomenon has been found in the attentional repulsion effect. Through systematic manipulation of the SOA in a vernier target judgment task similar to that of Suzuki and Cavanagh (1997), Ono and Watanabe (2011) have successfully demonstrated the "attentional attraction effect," in which the cue induced the perception[1] that it was attracting the target towards it, and such effect peaked when the cue was presented around 200 ms after the disappearance of the target bars. This

[1] In the experimental tasks concerned in the present paper and Ono and Watanabe (2011), we specifically refer the concept "perception" in the phenomenological sense of "how the target bars subjectively appear to the observer", in other words, the subjective visual localization regarding the relative positions of the target bars. For "awareness", we refer to "whether the observer is consciously aware of where the cue was presented on the screen".