Alerting and orienting of attention without visual awareness

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ABSTRACT

Two types of the attentional network, alerting and orienting, help organisms respond to environmental events for survival in the temporal and spatial dimensions, respectively. Here, we applied chromatic flicker beyond the critical fusion frequency to address whether awareness was necessary for activation of the two attentional networks. We found that high-frequency chromatic flicker, despite its failure to reach awareness, produced the alerting and orienting effects, supporting the dissociation between attention and awareness. Furthermore, as the flicker frequency increased, the orienting effect attenuated whereas the alerting effect remained unchanged. According to the systematic decline in temporal frequency sensitivity across the visual hierarchy, this finding suggests that unconscious alerting might be associated with activity in earlier visual areas than unconscious orienting. Since high-frequency flicker has been demonstrated to only activate early visual cortex, we suppose that neural activation in early visual areas might be sufficient to activate the two attentional networks.

1. Introduction

In nature, organisms have evolved so as to be sensitive to environmental events which may reveal new information about the visual environment and require immediate action accordingly. Two types of the attentional network, alerting and orienting (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Fernandez-Duque & Posner, 1997; Posner & Petersen, 1990; Raz & Buhle, 2006), cooperate and work together to help organisms maintain this sensitivity for survival in the temporal and spatial dimensions, respectively. Alerting refers to a state of enhanced response readiness in preparation for the imminent stimulus, whereas orienting is defined as the ability to selectively allocate attentional resources to a particular location of the visual field. Both the two attentional networks combine to influence the speed of responding to environmental events and then to produce an efficient and adaptive behavior.

An interesting question for understanding the relationship between attention and awareness is whether these attentional functions depend on visual awareness. In other words, when the attentional cue cannot be consciously perceived, is it still able to change the level of alertness and orient spatial attention to its location automatically? For the orienting aspect, previous studies regarding unconscious exogenous orienting have yielded mixed results (Mulckhuyse & Theeuwes, 2010). Some studies have shown that the subliminal cue can influence the distribution of spatial attention to a certain degree depending on the task relevance of the cue (Ansorge & Neumann, 2005; Ivanoff & Klein, 2003; McCormick, 1997). Some recent studies have shown that the subliminal cue is indeed capable of capturing attention in a stimulus-driven manner (

frames in the 120-Hz refresh rate condition), or 373 ms (56 refresh frames in the 150-Hz refresh rate condition), two square frames any transient change had occurred during the entire trial, including color change, luminance change, or flickering percept. They were told to respond as accurately as possible, without speed pressure. Each participant completed 60 invisible-flicker trials and 60 visible-flicker trials.

In Experiment 1, the participants in all the six experimental groups performed at ceiling level for the respective visible-flicker comparison (data not shown). By contrast, they performed at chance level for the respective invisible-flicker comparison with a mean correct percentage of 51.59% [$t(21) = 1.55$, $p > .135$], 52.05% [$t(21) = 1.61$, $p > .121$], and 51.67% [$t(21) = 1.37$, $p > .186$] for the Experiment 1a group in the 85-Hz, 120-Hz, and 150-Hz monitor refresh rate conditions, respectively, and 52.08% [$t(19) = 1.43$, $p > .167$], 51.58% [$t(19) = 1.37$, $p > .186$], and 50.83% [$t(19) = 0.85$, $p > .404$] for the Experiment 1b group

2.2. Results and discussion

2.2.1. Experiment 1a: unconscious alerting

In this experiment, the attentional cue occurred at the two possible target positions simultaneously (see Fig. 1). With such design, the attentional cue informed the participants that a target was about to appear, but provided no information about where the target would appear (Fan et al., 2002; Fernandez-Duque & Posner, 1997). The alerting effect referred to the extent to which RTs to targets following the attentional cue were faster than those to targets without the cue.

Not surprisingly, compared with the no cue condition, the visible chromatic flicker cues produced stable alerting effects at all SOAs (i.e., approximately 450, 650, and 900 ms for each experimental group) (for the 21.25-Hz cue: all ts > 3.15, ps < .006; the 20-Hz cue: all ts > 3.06, ps < .007; the 18.75-Hz cue: all ts > 2.43, ps < .025). Intriguingly, when the flicker cue was invisible, we obtained the same overall pattern of results for all the three experimental groups with respective invisible flicker frequency (see Fig. 3). An analysis of variance (ANOVA) with flicker frequency group (42.5, 60, and 75 Hz), SOA (450, 650, and 900 ms), and alerting (invisible cue and no cue) as factors on the RT data revealed a significant SOA × alerting interaction [F(2, 126) = 3.15, p < .05] but no significant SOA × alerting × group interaction [F(4, 126) = 0.56, p > .686]. For all invisible

2.2.2. Experiment 1b: unconscious orienting

In this experiment, the attentional cue occurred at one of the two possible target positions randomly (see Fig. 2), so that it had equal chance of being valid or invalid and did not predict the target position. Typically, the exogenous orienting of spatial attention should exhibit a biphasic pattern of initial facilitation followed by inhibition of return (IOR) (Klein, 2000; Posner & Cohen, 1984). That is, if this spatially uninformative cue is able to attract attention involuntarily, RTs for valid trials are faster than RTs for invalid trials at short SOAs, and slower for valid than invalid trials at longer SOAs.

Not surprisingly, the visible chromatic flicker cues produced a stable facilitation effect at the short 450-ms SOA [for the 21.25-Hz cue: $t(19) = 8.65$, $p < .001$; the 20-Hz cue: $t(19) = 6.86$, $p < .001$; the 18.75-Hz cue: $t(19) = 7.40$, $p < .001$]. When the flicker cue was invisible, however, the pattern of results differed across the three experimental groups with respective invisible flicker frequency (see Fig. 4). An ANOVA with flicker frequency group (42.5, 60, and 75 Hz), SOA (450, 650, and 900 ms), and cue validity (valid and invalid) as factors on the RT data revealed a significant SOA × validity interaction [$F(2, 114) = 4.30$, $p < .020$] but a marginally significant SOA × validity × group interaction [$F(4, 114) = 2.11$, $p = .091$]. For the 42.5-Hz cue, a significant interaction between SOA (450, 650, and 900 ms) and validity (valid and invalid) was found [$F(2, 38) = 7.35$, $p < .007$]. There was a significant facilitation effect at the short 450-ms SOA [$t(19) = 2.30$, $p < .034$], a marginally significant IOR effect at the middle 650-ms SOA [$t(19) = 1.93$, p

3. Experiment 2

In Experiment 1, we found not only the unconscious alerting and orienting effects, but also their distinct dependences on flicker frequency. However, one may argue that these unconscious attentional effects we observed in Experiment 1 could have been due to the offset of the flickering cue, rather than high-frequency chromatic flicker per se. This explanation seems possible for the following reasons. First, it is well known that the visual system is sensitive to events that exhibit transient

3.1.3. Both Experiments 2a and 2b

perceived, is effective in producing both the alerting and orienting effects. These findings provide further evidence for the dissociation between attention and awareness. According to the ecological perspective, it makes sense that both the two attentional networks may exert their functions even before conscious perception occurs. Such an automatic and rapid mechanism may supposedly facilitate the organism to deal with environmental events for survival.

Furthermore, the present findings also suggest that as the flicker frequency increases, the orienting effect of the invisible flicker attenuates whereas the alerting effect appears to be unaffected. Regarding the temporal processing capacity of the visual system, neurophysiological studies have demonstrated a systematic decline in temporal frequency sensitivity across the visual hierarchy. The primary visual cortex (V1) is sensitive to a much lower range of temporal frequencies than the lateral geniculate nucleus (Hawken et al., 1996). Likewise, the temporal processing capacity of the human visual cortex is progressively declined as visual information is transferred from early visual cortex to high cortex (McKeeff et al., 2007). Presumably, the greater frequency-dependent characteristic of the orienting versus alerting effect of the invisible flicker suggests that the neural mechanisms underlying the two unconscious attentional functions are likely to be different. Perhaps the unconscious alerting effect is associated with activity in earlier visual areas than the unconscious orienting effect.

When high-frequency flicker information is processed and transmitted along the visual pathway, despite its failure to reach visual awareness, it has been demonstrated to elicit cortical responses (Carmel, Lavie, & Rees, 2006; Falconbridge, Ware, & MacLeod, 2010; Gur & Snodderly, 1997; Jiang, Zhou, & He, 2007; Shady et al., 2004; Vul & MacLeod, 2006; Williams, Mechler, Gordon, Shapley, & Hawken, 2004). For instance, a psychophysical study has shown that the 30-Hz chromatic flicker induced flicker adaptation in human observers, suggesting that this invisible flicker could pass through the neural site for flicker adaptation (Shady et al., 2004). In another study, it is reported that even the 50-Hz color alternation could still induce the orientation contingent color aftereffect, which presumably arose from cortical mechanisms (Vul and MacLeod, 2006

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