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Research report

Increased visual task difficulty enhances attentional capture by both visual and auditory distractor stimuli

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ABSTRACT

Previous studies using a three-stimulus oddball task have shown the amplitude of P3a elicited by distractor stimuli increases when perceptual discrimination between standard and target stimuli becomes difficult. This means that the attentional capture by the distractor stimuli is enhanced along with an increase in task difficulty. So far, the increase of P3a has been reported when standard, target, and distractor stimuli were presented within one sensory modality (i.e., visual or auditory). In the present study, we further investigated whether or not the increase of P3a can also be observed when the distractor stimuli are presented in a different modality from the standard and target stimuli. Twelve participants performed a three-stimulus oddball task in which they were required to discriminate between visual standard and target stimuli. As the distractor stimuli, either another visual stimulus or an auditory stimulus was presented in separate blocks. Visual distractor stimuli elicited P3a, and its amplitude increased when visual standard/target discrimination was difficult, replicating previous findings. Auditory distractor stimuli elicited P3a, and importantly, its amplitude also increased when visual standard/target discrimination was difficult. This result means that attentional capture by distractor stimuli can be enhanced even when the distractor stimuli are presented in a different modality from the standard and target stimuli. Possible mechanisms and implications are discussed in terms of the relative saliency of distractor stimuli, influences of temporal/spatial attention, and the load involved in a task.

1. Introduction

Sensory events such as sudden changes or abrupt onsets attract our attention involuntarily even when they are unrelated to ongoing tasks. Such involuntary orienting of attention is called "attentional capture" (Theeuwes, 1991; Yantis and Egeth, 1999), which is thought to play an important role in detecting novel or potentially significant events in the surrounding environment.

In psychophysiological research with event-related brain potentials (ERPs), to examine the nature of attentional capture, several studies have used a three-stimulus oddball task (Courchesne et al., 1975; Katayama and Polich, 1996b). In this paradigm, standard stimuli with high probability (e.g., $p = 0.70$), target stimuli with low probability ($p = 0.15$), and distractor stimuli with low probability ($p = 0.15$) are presented in random order. Participants are required to respond (e.g., press a button) to target stimuli and not to respond to standard and distractor stimuli. In this task, both the target and the distractor stimuli elicit the P3 ERP component. The P3 elicited by the target stimuli is called "P3b," and is thought to reflect voluntary attentional allocation and evaluation of the target stimuli. The P3b shows a parietal scalp distribution with peak latency between 300 and 600 ms from onset of the stimuli (e.g., Donchin, 1981; Katayama and Polich, 1996a; Sutton et al., 1965). On the other hand, the P3 elicited by the distractor stimuli is called "P3a," and is thought to reflect attentional capture by the distractor stimuli (Escera et al., 1998; Friedman et al., 2001; Rushby et al., 2005; Sawaki and Katayama, 2008). The P3a shows more frontal scalp distribution with shorter peak latency compared with the P3b (Courchesne et al., 1975; Squires et al., 1975).

Several studies with a three-stimulus oddball task have shown that the P3a to distractor stimuli can be modulated as a function of perceptual task difficulty (i.e., perceptual load) as defined by discriminability between standard and target stimuli. When the discriminability between standard and target stimuli is low, and thus the task is difficult, the amplitude of the P3a elicited by

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distractor stimuli becomes larger compared to when the discriminability between standard and target stimuli is high and the task is easy (e.g., Comerchero and Polich, 1998, 1999; Katayama and Polich, 1998; Polich and Comerchero, 2003). The increased P3a is thought to reflect enhanced attentional capture by distractor stimuli, not enhanced inhibition of the processing of distractor stimuli (Sawaki and Katayama, 2007) or cognitive interference with maintaining the representation of standard stimuli (Sawaki and Katayama, 2008). Like the P3a, the P3b to target stimuli can also be modulated as a function of perceptual task difficulty. When the task is difficult, the amplitude and the peak latency of the P3b elicited by target stimuli become smaller and longer, respectively, compared to when the task is easy (e.g., Comerchero and Polich, 1998, 1999; Katayama and Polich, 1998; Polich and Comerchero, 2003). The decreased P3b is thought to reflect weakened memory representations or lowered internal discriminability of target stimuli (Kok, 2001).

So far, the task difficulty effect on the P3a has been demonstrated both when the three types of stimuli (i.e., standard, target, and distractor stimuli) were presented in the visual modality (e.g., Comerchero and Polich, 1998, 1999; Kimura et al., 2008; Polich and Comerchero, 2003; Sawaki and Katayama, 2006, 2007, 2008, 2009) or in the auditory modality (e.g., Combs and Polich, 2006; Comerchero and Polich, 1998, 1999; Katayama and Polich, 1998). In these previous studies, however, the three types of stimuli were always presented within one sensory modality (i.e., visual or auditory). Therefore, it is unclear whether or not the task-difficulty effect on P3a can occur even when the distractor stimuli are presented in a different modality from the standard and target stimuli.

To answer this question, the present study investigated the P3a to visual and auditory distractor stimuli when participants were required to discriminate between visual standard and target stimuli. Participants performed three-stimulus oddball tasks in which they discriminated visual standard stimuli ($p = 0.70$) and visual target stimuli ($p = 0.15$) differing in size. We set easy and difficult task conditions by manipulating the extent of the size difference, in separate blocks. As distractor stimuli ($p = 0.15$), another visual stimulus and an auditory stimulus were presented in the visual and auditory distractor conditions, respectively, in separate blocks. We examined the P3a to the distractor stimuli and P3b to the target stimuli in the four conditions (i.e., combinations of the two difficulty levels and two distractor modalities).

It was expected that the amplitude of the P3a to visual distractor stimuli should increase and the P3b to visual target stimuli should decrease in the difficult condition compared with easy condition, as repeatedly shown in previous studies with a three-stimulus oddball task (e.g., Comerchero and Polich, 1998, 1999; Kimura et al., 2008; Polich and Comerchero, 2003; Sawaki and Katayama, 2006, 2007, 2008, 2009). On the other hand, there are several possible ways the visual task difficulty may affect the P3a to auditory distractor stimuli. One possibility is that the amplitude of the P3a increases in the difficult condition; this means that the attentional capture by the auditory distractor stimuli is enhanced by the increase in visual task difficulty. It is also possible that the amplitude of the P3a decreases or shows no modulation in the difficult condition; this means that the attentional capture by the auditory distractor stimuli is degraded or not affected by the increase in visual task difficulty, respectively. These latter possibilities can be expected in light of some previous studies (Harmony et al., 2000; Muller-Gass et al., 2007). In these studies, frequent and infrequent task-irrelevant auditory stimuli were presented while participants were performing a visual task (i.e., a continuous visual tracking task or a letter re-ordering task). The infrequent auditory stimuli elicited P3a, and its amplitude decreased (Harmony et al., 2000) or showed no modulation (Muller-Gass et al., 2007) in response to the increase in visual task difficulty.

As an additional analysis, we also examined the effects of task difficulty on the amplitude of the auditory N1 to the auditory distractor stimuli. The purpose of this analysis was to examine whether or not the possible modulation of attentional capture by the auditory distractor stimuli indexed by P3a is preceded by the modulation of early auditory processing indexed by the auditory N1 (cf. Sabri et al., 2006).

2. Results

2.1. Performance

Table 1 shows the data on the behavioral performance in each condition. For the reaction times in response to target stimuli, a two-factor (2 Distractor × 2 Difficulty) ANOVA revealed a significant main effect of difficulty, showing a longer reaction time in the difficult condition, $F(1, 11) = 94.65$, $p < 0.001$, $\eta_p^2 = 0.90$. For the hit rate for target stimuli, the ANOVA revealed a significant main effect of difficulty, showing a lower hit rate in the difficult condition, $F(1, 11) = 59.61$, $p < 0.001$, $\eta_p^2 = 0.84$. For the false alarm rate for both standard and distractor stimuli, no main effect or interaction was obtained, $Fs < 2.83$, $ps > 0.12$ and $Fs < 2.20$, $ps > 0.16$, respectively.

2.2. P3a to visual and auditory distractor stimuli

Fig. 1 shows the grand-averaged ERP waveforms from the four midline electrodes (i.e., Fz, Cz, Pz, and Oz) in response to the standard, target, and distractor stimuli in each condition. Figs. 2 and 3 show the mean amplitudes and topographic maps. Both the visual and auditory distractor stimuli elicited P3a, and its amplitude seems to be larger in the difficult condition compared with the easy condition in both the visual and auditory distractor conditions.

For the mean amplitude of the P3a, a three-factor ANOVA (2 Distractor × 2 Difficulty × 4 Electrode) revealed significant main effects of difficulty, $F(1, 11) = 36.70$, $p < 0.001$, $\eta_p^2 = 0.77$, and electrode, $F(3, 33) = 18.88$, $p < 0.001$, $\varepsilon = 0.49$, $\eta_p^2 = 0.63$. The ANOVA also revealed significant interactions of distractor × electrode, $F(3, 33) = 9.82$, $p = 0.003$, $\varepsilon = 0.52$, $\eta_p^2 = 0.47$, and difficulty × electrode, $F(3, 33) = 7.06$, $p = 0.006$, $\varepsilon = 0.58$, $\eta_p^2 = 0.39$. Main effect of distractor, $F(1, 11) = 0.05$, $p = 0.82$, $\eta_p^2 = 0.005$, and interactions of distractor × difficulty, $F(1, 11) = 3.54$, $p = 0.09$, $\eta_p^2 = 0.24$, and distractor × difficulty × electrode, $F(3, 33) = 2.42$, $p = 0.12$, $\eta_p^2 = 0.18$, were not significant.

The main effect of difficulty showed that the P3a amplitude was larger in the difficult condition than in the easy condition. The post hoc comparison for the main effect of electrode showed that the P3a amplitudes at Cz, Pz, $ps < 0.001$, and Oz, $p = 0.046$, were larger compared with those at Fz, and the amplitude at Pz was larger compared with Oz, $p = 0.026$. The post hoc comparison for the interaction of distractor × electrode showed that the P3a amplitude in response to the visual distractor stimuli was larger at Cz and Pz compared with Fz, $ps < 0.001$, whereas the P3a amplitude in response to the auditory distractor stimuli was larger at Cz compared with all other electrodes, $ps < 0.010$, and the P3a amplitude at Pz was larger compared with Fz and Oz, $ps < 0.008$. This means that the scalp distribution of P3a differed between the two types of distractor stimuli. The post hoc comparison for the interaction of difficulty × electrode showed that the P3a amplitude was larger in the difficult condition than in the easy condition at all the electrode sites, $ps < 0.001$. This means that the P3a amplitude was larger in difficult condition than in the easy condition at all electrodes, although the degree of the effects of the task difficulty might be different among electrodes.