

Orienting and Focusing in Voluntary and Involuntary Visuospatial Attention Conditions

An Event-Related Potential Study

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Abstract. In the present study, we used event-related potentials (ERPs) and behavioral measurements in a peripherally cued line-orientation discrimination task to investigate the underlying mechanisms of orienting and focusing in voluntary and involuntary attention conditions. Informative peripheral cue (75% valid) with long stimulus onset asynchrony (SOA) was used in the voluntary attention condition; uninformative peripheral cue (50% valid) with short SOA was used in the involuntary attention condition. Both orienting and focusing were affected by attention type. Results for attention orienting in the voluntary attention condition confirmed the “sensory gain control theory,” as attention enhanced the amplitude of the early ERP components, P1 and N1, without latency changes. In the involuntary attention condition, compared with invalid trials, targets in the valid trials elicited larger and later contralateral P1 components, and smaller and later contralateral N1 components. Furthermore, but only in the voluntary attention condition, targets in the valid trials elicited larger N2 and P3 components than in the invalid trials. Attention focusing in the involuntary attention condition resulted in larger P1 components elicited by targets in small-cue trials compared to large-cue trials, whereas in the voluntary attention condition, larger P1 components were elicited by targets in large-cue trials than in small-cue trials. There was no interaction between orienting and focusing. These results suggest that orienting and focusing of visual-spatial attention are deployed independently regardless of attention type. In addition, the present results provide evidence of dissociation between voluntary and involuntary attention during the same task.

Keywords: attention, orienting, focusing, voluntary, involuntary, ERP

Introduction

Previous studies have shown a difference between orienting and focusing of attention in different tasks and have demonstrated that these two processes can be elicited in both voluntary and involuntary conditions (Berger, Henik, & Rafal, 2005; Hopfinger & West, 2006; Müller & Rabbitt, 1989; Turatto et al., 2000).

Turatto et al. (2000) suggested that focusing is different from orienting in two aspects: First, a sudden onset stimulus does not disturb orienting, whereas focusing can automatically adjust to a new object size. Second, orienting can be elicited by either an onset or an offset transient signal, while focusing can only be triggered by a sudden onset.

Attention involves two different systems: the voluntary (or endogenous) system and involuntary (or exogenous) system (Posner, 1980). Previous studies (Cheal & Lyon, 1991; Gowen, Abadi, Poliakoff, Hansen, & Miall, 2007;

Hawkins, Hillyard, Luck, Mouloua, & Downing, 1990; Jonides, 1981; Müller & Rabbitt, 1989; Posner, 1980) investigated the distinction between these two attention systems and showed that voluntary attention is an endogenous, volitionally controlled, top-down process that is always associated with central symbolic cues; subjects could decide where to focus their attention. In contrast, involuntary attention is an exogenous, automatic reflexive, bottom-up process that is elicited by abrupt peripheral cues, and cue validity effects occurred even when the cue was uninformative (Doallo et al., 2004; Riggio & Kirsner, 1997).

For orienting, even under covert attention conditions, faster and more accurate responses were found with cued locations (Fu, Caggiano, Greenwood, & Parasuraman, 2005; Müller & Rabbitt, 1989; Posner, 1980). Posner attributed this effect to enhanced sensory processing of the attended stimuli. In previous ERP studies (Fu et al., 2005; Hopfinger & West, 2006), attention enhanced the neural

activity at cued locations in both the voluntary and involuntary attention conditions. P1 and N1 components are the most common ERP components modulated by attention in visual attention tasks. The P1 component, located in the extrastriatal cortex, is considered to be the earliest influence of spatial attention on visual processing (Fu et al., 2008). Compared with targets in invalid trials, targets in valid trials usually elicit larger P1 components (80–120 ms) over the posterior scalp areas in both voluntary and involuntary attention conditions (Clark, Fan, & Hillyard, 1995; Clark & Hillyard, 1996; Fu, Fan, Chen, & Zhuo, 2001; Fu et al., 2005; Mangun, 1995; Yamaguchi, Tsuchiya, & Kobayashi, 1994). These enhanced P1 components reflect a sensory-gain control mechanism that results in enhanced perceptual processing of attended stimuli (Mangun & Hillyard, 1990; Mangun, Hillyard, & Luck, 1993). Previous studies (Fu et al., 2005; Mangun, 1995; Mangun & Hillyard, 1990) have suggested that N1 components had opposite responses in voluntary and involuntary attention conditions. In the voluntary attention condition, compared with invalid trials, targets in valid trials elicited larger N1 components, while in the involuntary attention condition, the contralateral N1 component amplitude was smaller in valid trials relative to invalid trials (Fu et al., 2001). In addition, the latencies of P1 and N1 components were not influenced by an attentional effect in the voluntary attention condition, however, in the involuntary attention condition later contralateral P1 and N1 components were found in valid cue trials as compared to invalid cue trials. N2 and P3 components were also found in the cue-target attentional paradigm. The N2 component reflected the attentional preparation for the decision process. Larger N2 component amplitudes were elicited by targets in valid cue trials relative to invalid cue trials in a spatial attention task (Mangun, Hillyard, & Luck, 1993). This could be related to executive processes in attention. Larger N2 amplitudes were also elicited by deviant stimuli in the occipital region in previous temporal attention studies, and was attributed to a response inhibition caused by distraction (Correa, Lupiáñez, Madrid, & Tudela, 2006; Griffin, Miniussi, & Nobre, 2002 [Experiment 2]). P3 components are signals of late stage processing. Previous studies (Anllo-Vento, 1995; Hillyard, Luck, & Mangun, 1994; Hopfinger & Mangun, 1998; Hopfinger & West, 2006) have provided evidence for a dissociation of the voluntary and involuntary attention effects on P3 components. Larger P3 amplitudes to validly cued stimuli (relative to invalidly cued stimuli) have been reported in the voluntary attention condition but not in the involuntary attention condition by Hopfinger and West (2006). Larger P3 components elicited by targets in invalid trials than in valid trials were found for informative peripheral cues with long cue-target SOAs tasks (Hillyard et al., 1994: cue validity 75%, SOA 600–800 ms; Anllo-Vento, 1995: cue validity 70%, SOA 600 ms). Moreover, in the Hopfinger and Mangun (1998) study, larger P3 amplitudes to valid trials (relative

to invalid trials) were found under uninformative peripheral cueing conditions with short SOAs (68–268 ms).

The zoom lens model has been used to describe focusing of attention (Eriksen & St. James, 1986; Eriksen & Yeh, 1985). In this model, the zoom lens can cover a variable portion of the visual space. The focus size can be changed, the concentration allocated to a given area can be modified, and the resolution improves when given regions are focused (Eriksen & St. James, 1986). Typical cue size or scaling effects indicate that a larger distribution or focus of attention in space slows processing as compared to a smaller distribution of focus. There was an inverse relationship between the size of attentional focus and efficiency of processing: When the size of the cued area increased, the response speed decreased (Castiello & Umiltà, 1990; Greenwood & Parasuraman, 1999; Luo, Greenwood, & Parasuraman, 2001). Castiello and Umiltà (1990) have shown that the cue size effect will disappear when the cue to target SOA is less than a certain threshold (40 ms).

Previous studies have examined ERP responses associated with the focusing of attention. Luo et al. (2001), using a voluntary attention task with differently scaled cues, found that a less precisely cued target (large cue) elicited larger P1 components and smaller N1 components than a more precisely cued target (small cue). Changes to the P1 components reflected the additional computations required for changing the spatial scale of attention to the appropriate element size to facilitate target discrimination. The decrease in N1 components according to cue size may reflect a broadening of the spatial gradient of attention (Luo et al., 2001). However, Fu et al. (2005) used a peripheral cueing task and found a negative cue-size effect (larger cue with short response times) and that smaller cues elicited larger P1 components. The two studies used different attention types. Luo used a voluntary attention paradigm while Fu used an involuntary attention paradigm. The contrasting results of their studies may reflect differences between voluntary and involuntary attention. Because the different results were coming from separate studies, we performed an experiment that included both voluntary and involuntary attention conditions to look for more clear and decisive evidence for the relationship of voluntary and involuntary attention.

Both voluntary and involuntary attention could be elicited in peripheral cueing tasks. Because the peripheral cueing task differs from the central cueing task, the cue validity is dependent on SOA (Cheal & Lyon, 1991; Fu et al., 2001). In the peripheral cueing task, when the SOA is within 300 ms, especially between 50–100 ms, a fast automatic shift of attention (involuntary attention) occurs (Fu et al., 2005; Müller, 1994) and valid peripheral cues trigger a short reaction time (Posner & Cohen, 1984). When the SOA is 300 ms or more and the cue is uninformative, “inhibition of return (IOR)” occurs and the reaction times to the targets in valid trials are slower than the reaction times to the targets in invalid trials (Posner & Cohen, 1984). At

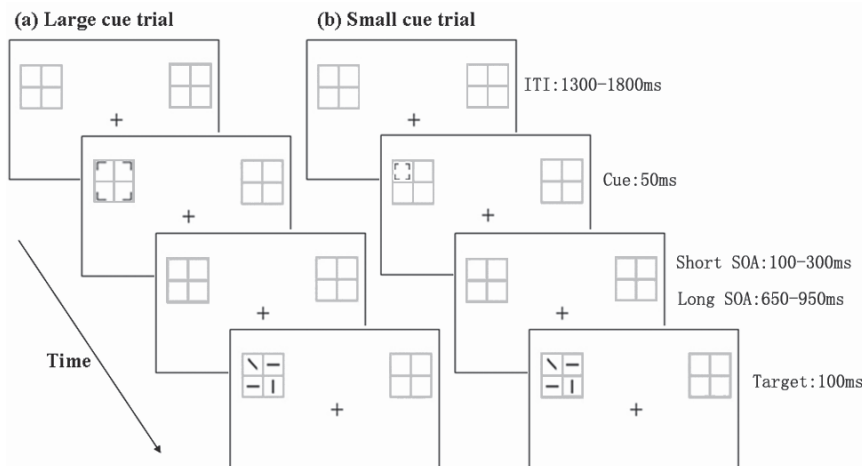


Figure 1. The procedure of the experimental paradigm in a large cue trial (a) and a small cue trial (b).

longer cue-to-target SOAs, with informative cues (validity more than 50%), a voluntary-attention allocating mechanism, similar to that involved in the central cueing task, is activated (Müller & Rabbitt, 1989). As informative peripheral cues can elicit voluntary attention, we can use the peripheral cues with long SOAs as a substitute for symbolic central cues to study voluntary and involuntary attention in one experimental design.

The present study used ERP to investigate the relationship between focusing and orienting in voluntary and involuntary attention conditions in one task. We used a cue-target paradigm in our study, and focused on the early P1, N1 and late N2, P3 components. In the present study, orienting is indicated by the cue validity effect and refers to the ability to move the attentional focus in visual space. Focusing is indicated by the cue size effect and refers to the ability to adjust the attentional focus size in visual space. Voluntary and involuntary attention are indicated by different cue-to-target SOAs in a peripheral cueing task. Voluntary attention is elicited by longer SOAs with informative cues while involuntary attention is elicited by shorter SOAs with uninformative cues (Fu et al., 2005). Instead of comparing the responses of different groups in different tasks, we were able to assess both voluntary and involuntary attention in the same group with a single task. We addressed two questions in our study: (1) Orienting and focusing were compared directly to determine whether these two processes occur independently in both voluntary and involuntary attention. Can cue size modulate cue validity or can cue validity modulate cue size? That means, was there any interaction between focusing and orienting? (2) The relationship between voluntary and involuntary attention was assessed in a single task to investigate if there is any interaction between them. Fu et al. (2005) reasoned that similar ERP components point to similar underlying neural processes, so if the P1, N1, N2, and P3 components were modulated by orienting and focusing in voluntary and involuntary attention in different ways, they were separate and have different underlying mechanisms.

Methods

Participants

A total of 21 healthy undergraduate students (12 female and 9 male), ages ranging from 18 to 23, participated in this experiment. They were paid after the test. All the participants were right-handed and reported normal or corrected-to-normal vision. None of them had a history of psychiatric or neurological disorders. Three of the participants were excluded during the data analysis because of the low accuracy rate, eye movement, or a noisy wave, so finally we used the data from 18 participants (10 female, 8 male) age between 18–23 years old (Mean 20.8).

Stimuli

A modified visual cue-target task (Figure 1) was used. A black fixation cross ($0.5^\circ \times 0.5^\circ$) and two gray frames were presented continuously throughout the task. The fixation cross was at the center of a white computer screen and the two gray frames ($3.4^\circ \times 3.4^\circ$) were positioned on the left and right sides of the screen (center 6.02° lateral to 2.63° above the fixation cross). Each frame had 2×2 grids. The search array ($2.6^\circ \times 2.6^\circ$) had four black lines: two horizontal (“–”), one vertical (“|”), and one diagonal (which could be backward “\” or forward “/”); each line was included in one grid. The search array center location was the same as the frame center. The target lasted 100 ms and was preceded by a black cue that lasted 50 ms. All cues had four corners as a Kanizsa box (with each corner subtending $0.24^\circ \times 0.24^\circ$ of visual angle). Half of the cues were small (with the illusory rectangle created by the four dots subtending $1.15^\circ \times 1.15^\circ$) and half of them were large ($2.9^\circ \times 2.9^\circ$). The cue appeared randomly at either the left or right side. Large cues were centered at the same location as the frame and search array; when the large cue appeared at the same location as the search array the cue was valid,

when the cue appeared at the opposite side it was invalid. Small cues were located randomly in one of the grids of each frame. When the small cue appeared at the same location as the diagonal line it was valid, but when the small cue and the search array appeared at opposite sides it was invalid, the small cue and the diagonal line were always in the same quadrant. The cue-to-target SOA was varied randomly over two ranges of intervals: short (100–300 ms) for the involuntary attention condition and long (650–950 ms) for the voluntary attention condition. In the involuntary attention condition, the cue validity was 50%. In the voluntary attention condition, the cue validity was 75%. The intertrial interval (ITI) was 1300–1800 ms.

Procedure

Participants were seated in a comfortable armchair in a quiet, dimly lit, and electrically isolated room. During the experiment, they were asked to sit in a relaxed position, fixate their eyes on the fixation cross, and minimize eye blinks and body movement. The horizontal distance from their eyes to the fixation cross was 70 cm. The participants were required to respond to all diagonal lines in the search arrays. Both accuracy and response speed were emphasized during instruction. Participants were instructed to use their right index finger to press the key “J” on the keyboard when the backward line “\” appeared and to use their left index finger to press the key “F” on the keyboard when the forward line “/” appeared. Before the EEG recording, the experiment was explained to the participants and they were allowed practice sessions. The experiment had two different sessions (short SOA session and long SOA session). The sequences of the two sessions were evenly distributed across the participants. There were 24 blocks in the short SOA session and 48 blocks in the long SOA session. Each block had 40 trials that were presented randomly. The participants were required to take a rest after each block (duration of rest decided by participants).

ERP Recording

A 64-channel system was used in this experiment, electroencephalogram (EEG) was recorded from 64 scalp sites using Ag/AgCl electrodes mounted in an elastic cap (Neuroscan Inc.), with references on the left and right mastoids. The vertical electrooculogram (VEOG) was recorded with electrodes placed above and below the left eye. The horizontal electrooculogram (HEOG) was monitored by placing two electrodes 10 mm from the outer canthi of both eyes. All interelectrode impedances were maintained below 5 k Ω . Signals were amplified with a 0.1–40 Hz bandpass filter and digitized at 500 Hz. Reaction times were recorded for each trial.

Data Analysis

Behavioral data were analyzed by means of repeated measures analysis of variances (ANOVAs).

The EEG data were digitally filtered with 30 Hz lowpass and were epoched into periods of 1000 ms, from 200 ms prior to the onset of the target to 800 ms posttarget and from 200 ms prior to the onset of the cue to 800 ms postcue. Ocular artifacts were removed from the EEG signal using a regression procedure implemented in the Neuroscan software (Semlitsch, Anderer, Schuster, & Presslich, 1986). Trials with body movements and muscle activity were rejected, with a criterion of ± 75 μ V. The ERPs were then averaged separately for all experimental conditions. Trials with response errors were excluded from analysis. The ADJAR algorithm (Woldorff, 1993) was used to minimize the overlap by the cues.

Peak amplitudes and peak latencies were used for statistical analyses on P1, N1, and N2 components. Average amplitude analysis was used on the P3 component. The time windows for P1, N1, N2, and P3 components were 90–160 ms, 150–230 ms, 220–320 ms, and 350–450 ms, respectively. EEGs for the cues and the targets were averaged separately from the time point of their onset. EEGs were averaged separately for all combinations of task conditions (cue-to-target SOA: short or long; cue size: small or large; trial validity: valid or invalid; visual field: left or right). The incorrect response trials were excluded for averaging. ANOVAs were used for the ERP data analysis. The Greenhouse-Geisser correction was used to compensate for sphericity violations. Post hoc analyses were conducted to explore the interaction effects.

Results

Behavior Results

The accuracy rate was high in both the voluntary and involuntary attention conditions. It was 96.3% in the involuntary attention (short SOA) condition and 96.6% in the voluntary attention (long SOA) condition. ANOVA was used for behavior data analysis; the factors were cue size, cue-to-target SOA, validity, and visual field. The main effect of cue validity was significant, $F(1, 17) = 79.46, p < .001$. Compared with invalid cue trials, participants responded faster to targets in valid trials (487 vs. 512.78 ms; Figure 2). The cue-size main effect was significant, $F(1, 17) = 13.69, p < .005$, with the participants responding moderately faster to the targets preceded by small cues relative to targets preceded by large cues (495.53 vs. 504.25 ms). The SOA \times cue size interaction was significant, $F(1, 17) = 16.01, p < .001$, indicating that in the voluntary attention condition, compared with targets in large-cue trials, the response time for targets in small-cue trials is faster, $F(1, 17) = 19.29, p < .001$. No other main effects or interactions were significant.

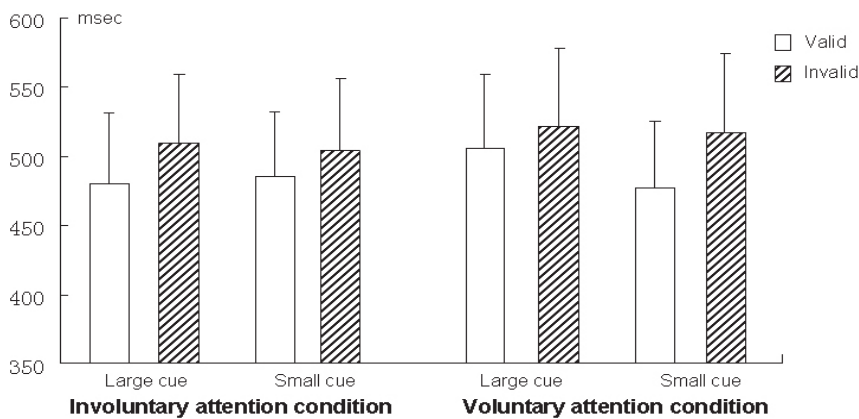


Figure 2. The mean reaction time (RT) and standard errors for cue validity and cue size effects in the voluntary and involuntary attention conditions.

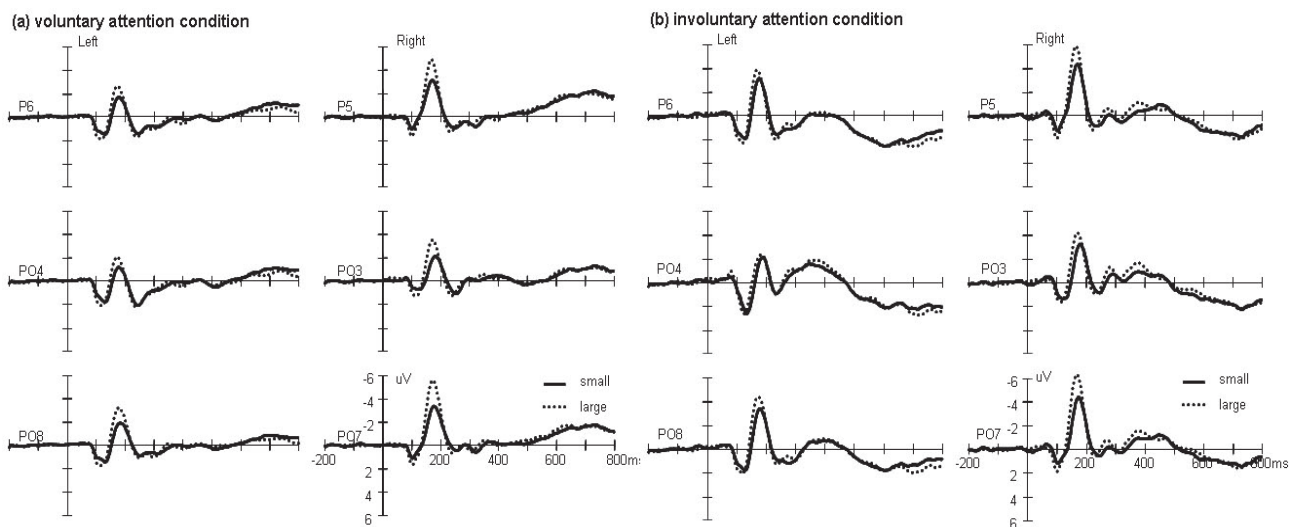


Figure 3. The grand average of ERP in the voluntary (a) and involuntary attention (b) condition elicited by the large (dots lines) and small cues (real lines) at the posterior contralateral sites when the cues appeared in the left and right visual field. Data were averaged across the valid and invalid cues.

ERP Elicited by the Cue

ANOVA was used for ERP components, the factors were cue size (2 levels: large or small), visual field (2 levels: left or right), hemisphere (2 levels: left or right) and electrode site (6 sites for P1, N1 components: P5, P6, PO3, PO4, PO7, PO8).

Cue size had a significant effect on P1 amplitude, $F(1, 17) = 7.22, p < .05$. The visual field \times cue size \times hemisphere interaction was significant, $F(1, 17) = 13.69, p < .01$, indicating that large cues elicited larger P1 component amplitudes at the contralateral temporal sites (Figure 3); no other main effects and interactions were significant.

Cue size had a significant effect on N1 amplitude, $F(1, 17) = 25.29, p < .001$. The visual field \times cue size \times hemisphere interaction was significant, $F(1, 17) = 37.31, p < .001$, indicating that larger N1 were elicited by large cues at contralateral temporal sites in both voluntary and involuntary attention conditions (Figure 3).

ERPs Elicited by the Target

ANOVA was used for ERP components, the factors were cue size (2 levels: large or small), cue-to-target SOA (2 levels: short or long), validity (2 levels: valid or invalid), visual field (2 levels: left or right), hemisphere (2 levels: left or right) and electrode site (six sites for P1, N1, N2, and P3 components: P5, P6, PO3, PO4, PO7, PO8).

P1 Component

Cue Validity Effect

SOA had a significant effect on P1 amplitude, $F(1, 17) = 6.76, p < .05$. The P1 component was larger in the voluntary attention condition than the involuntary attention condition (2.58 ± 0.32 vs. $1.65 \pm 0.34 \mu\text{V}$; Figures 4 and 5). The visual field \times validity \times hemisphere interaction was

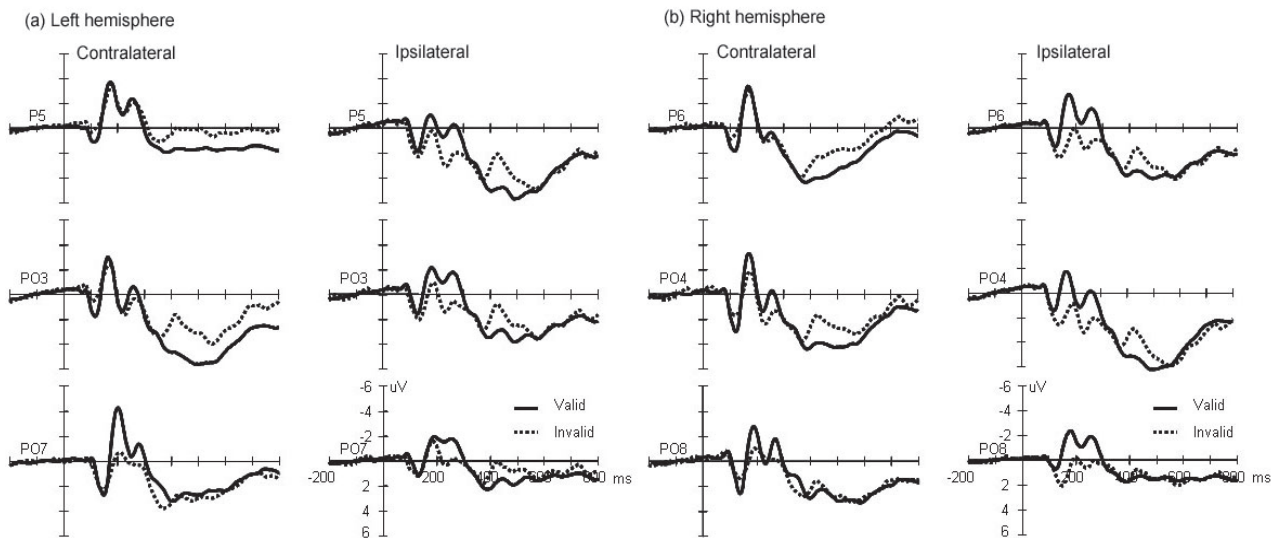


Figure 4. The average of ERPs elicited by the valid (real lines) and invalid (dots lines) trials in the left (a) and right (b) hemisphere at the contralateral and ipsilateral sites in the voluntary attention condition (long SOA). Data were averaged across cue size.

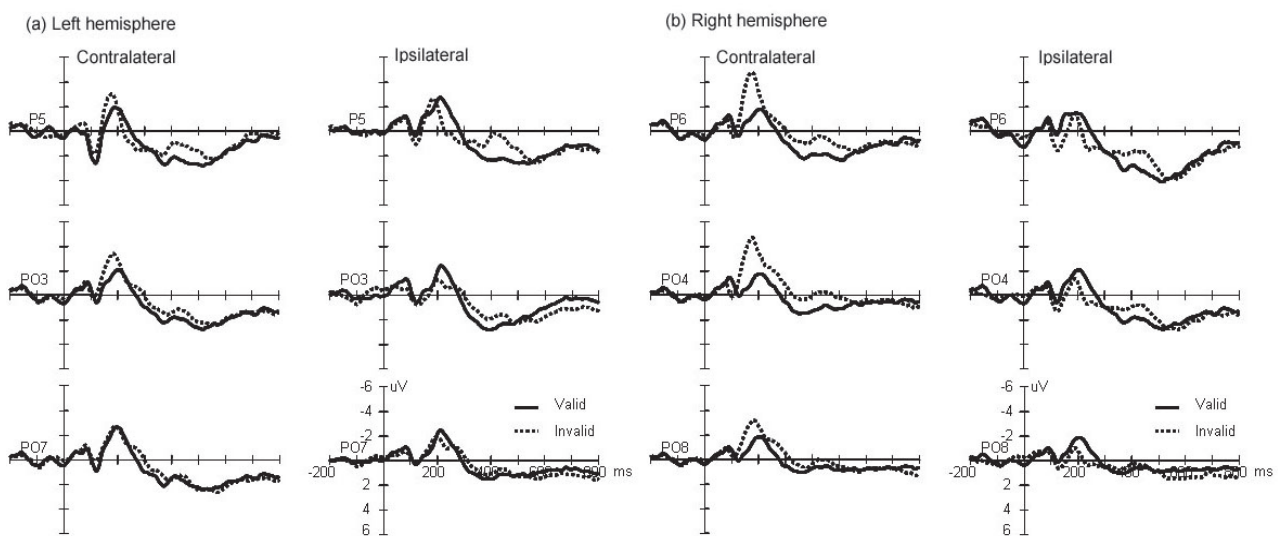


Figure 5. The average of ERP elicited by the valid (real lines) and invalid (dots lines) trials from left (a) and right (b) hemisphere at the contralateral and ipsilateral sites in the involuntary attention condition (short SOA). Data were averaged across cue size.

significant in both the voluntary, $F(1, 17) = 8.55, p < .01$, and involuntary attention conditions, $F(1, 17) = 24.48, p < .001$. Furthermore, larger P1 components elicited by targets in valid trials relative to invalid trials were found at contralateral sites in both the voluntary, $F(1, 17) = 20.83, p < .01$ (2.57 ± 0.3 vs. $2.03 \pm 0.3 \mu\text{V}$), and involuntary attention conditions, $F(1, 17) = 49.07, p < .001$ (1.42 ± 0.3 vs. $0.91 \pm 0.4 \mu\text{V}$). Also, the cue-validity effect was apparent for data averaged across the cue size (Figure 4 and Figure 5).

SOA had a significant effect on P1 latency, $F(1, 17) = 25.34, p < .001$. The SOA \times visual field \times validity \times hemisphere interaction was significant, $F(1, 17) = 17.89, p < .01$. Furthermore, the visual field \times validity \times hemisphere interaction was significant in the involuntary attention condition, $F(1, 17) = 8.19, p < .05$. The P1 component was later at contralateral temporal sites in the valid trials relative to invalid trials (122 ± 2.3 vs. 108 ± 1.6 ms). In the voluntary attention condition, the P1 latency was not changed.

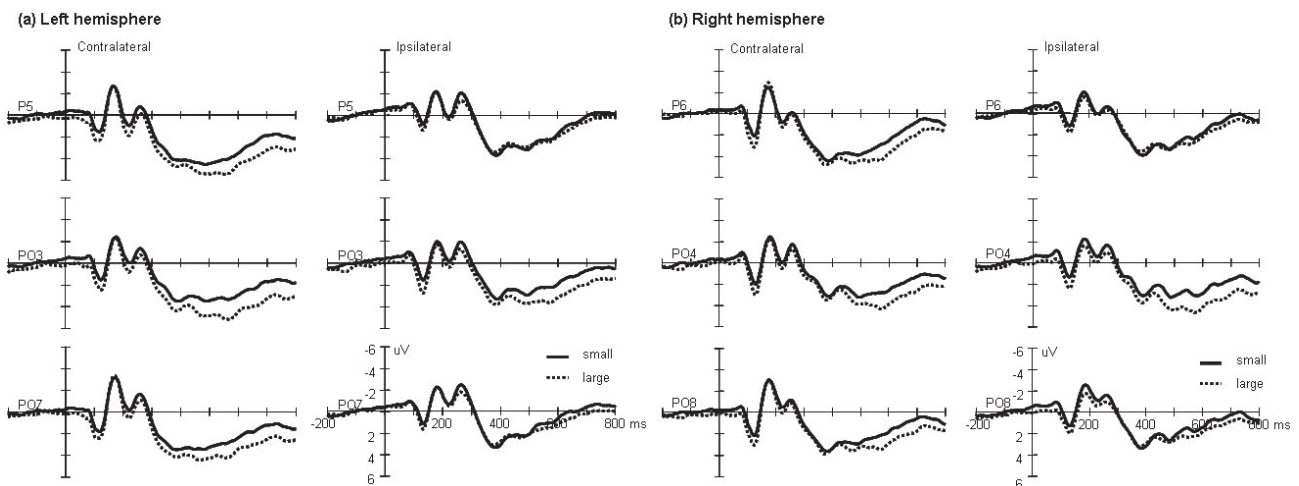


Figure 6. The average of ERP elicited by the small (real lines) and large (dots lines) trials from left (a) and right (b) hemisphere at the contralateral and ipsilateral sites in the voluntary attention condition (long SOA). Data were averaged across cue validity.

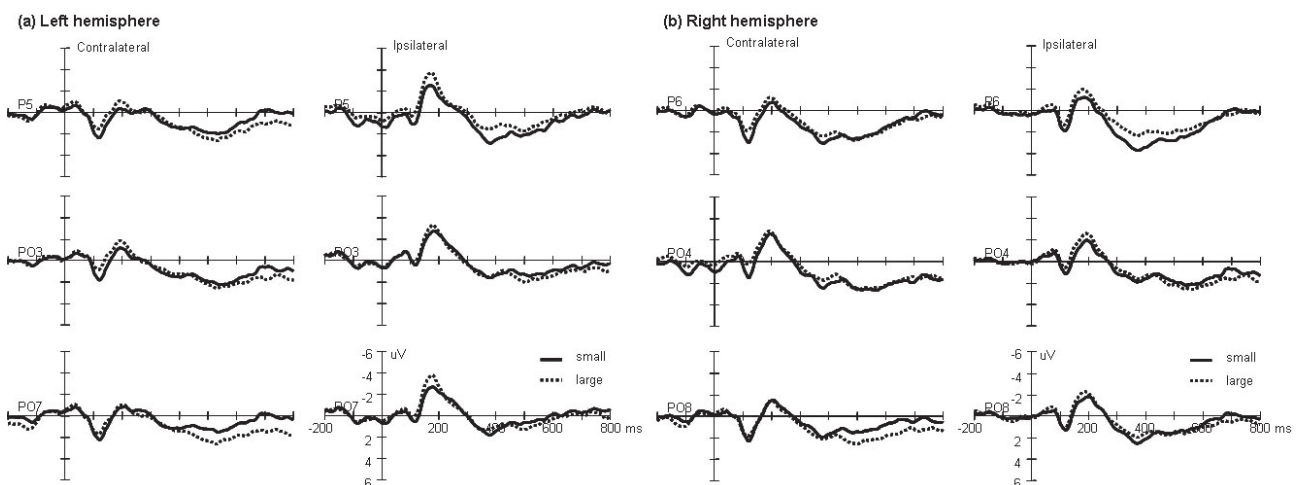


Figure 7. The average of ERP elicited by the small (real lines) and large (dots lines) trials from left (a) and right (b) hemisphere at the contralateral and ipsilateral sites in the involuntary attention condition (short SOA). Data were averaged across cue validity.

Cue Size Effect

The SOA \times cue size interaction was significant for P1 amplitude, $F(1, 17) = 8.72, p < .01$, indicating that attention type affected the cue size effect on the P1 component. In the involuntary attention condition, compared with large-cue trials, marginally larger P1 components were elicited by targets in small-cue trials, $F(1, 17) = 4.13, p < .05$ (1.83 ± 0.33 vs. $1.47 \pm 0.37 \mu\text{V}$). In the voluntary attention condition, however, larger P1 component were elicited by targets in large-cue trials than in small-cue trials, $F(1, 17) = 4.52, p < .05$ (2.66 ± 0.33 vs. $2.5 \pm 0.31 \mu\text{V}$; Figure 6 and Figure 7).

The SOA \times cue size interaction was significant for P1 latency, $F(1, 17) = 6.26, p < .05$. However, further analysis

showed there was no main effect or interaction in both the voluntary and involuntary conditions. The interaction between cue size and validity was not significant for P1 amplitude, $F(1, 17) = 3.86, p < .1$, and latency, $F(1, 17) = 3.44, p < .1$.

N1 Component

Cue Validity Effect

The SOA \times validity interaction was significant for N1 amplitude, $F(1, 17) = 7.87, p < .05$. The SOA \times visual field \times validity \times hemisphere interaction was also significant for N1 amplitude, $F(1, 17) = 5.72, p < .05$. Further analysis showed that, in the involuntary attention condition, the vis-

ual field \times validity \times hemisphere interaction was significant, $F(1, 17) = 4.77, p < .05$; compared with valid cue trials, invalid trials elicited larger N1 at contralateral temporal sites, $F(1, 17) = 51.96, p < .001$ (-3.51 ± 0.41 vs. $-0.91 \pm 0.36 \mu\text{V}$). In the voluntary attention condition, compared with invalid trials larger N1 were elicited by targets in valid trials at both contralateral, $F(1, 17) = 33.96, p < .001$ (-4.87 ± 0.6 vs. $-0.81 \pm 0.51 \mu\text{V}$), and ipsilateral, $F(1, 17) = 41.62, p < .001$ (-3.84 ± 0.57 vs. $-1.84 \pm 0.34 \mu\text{V}$), temporal sites.

SOA had a significant effect on N1 latency, $F(1, 17) = 9.18, p < .05$, indicating that target latency in the involuntary attention condition was later than in the voluntary attention condition. The interaction between SOA and validity effect was significant, $F(1, 17) = 51.73, p < .001$; involuntary-attention condition targets in valid trials elicited a later N1 than in invalid trials. The validity main effect was significant, $F(1, 17) = 7.64, p < .05$. The SOA \times visual field \times validity \times hemisphere interaction was significant, $F(1, 17) = 12.23, p < .001$. Furthermore, in the involuntary attention condition, the visual field \times validity \times hemisphere interaction was significant, $F(1, 17) = 4.37, p < .05$. Later N1 elicited by targets in valid trials relative to invalid trials were found at contralateral temporal sites, $F(1, 17) = 19.87, p < .001$ (199.67 ± 3.55 vs. 184.96 ± 2.72 ms). In the voluntary attention condition no other main effect or interaction was found, and the N1 latency was not changed.

Cue Size Effect

Larger N1 components were elicited by targets in large-cue trials than in small-cue trials, $F(1, 17) = 5.16, p < .05$ (-3.01 ± 0.41 vs. $-2.91 \pm 0.43 \mu\text{V}$), in the involuntary attention condition. The interaction between cue size and validity was not significant for N1 amplitude, $F(1, 17) = 0.14, p < 1$, or latency, $F(1, 17) = 0.012, p < 1$. No other significant main effect or interactions were found.

N2 Component

SOA had a significant effect on N2 amplitude, $F(1, 17) = 7.23, p < .05$; the N2 amplitudes were larger in the voluntary attention condition than in the involuntary attention condition (Figures 4, 5). The main effect of validity was significant, $F(1, 17) = 28.33, p < .001$, compared with targets in invalid trials, valid-cue trials elicited larger N2 component (-2.05 ± 0.38 vs. $-1.28 \pm 0.37 \mu\text{V}$). Cue size also had a significant effect on N2 amplitude, $F(1, 17) = 11.25, p < .005$; compared with targets in the large-cue trials, smaller-cue trials elicited larger N2 component (-1.8 ± 0.36 vs. $-1.54 \pm 0.38 \mu\text{V}$; Figures 6, 7). The interaction between SOA and validity effect was significant, $F(1, 17) = 12.43, p < .005$. Furthermore, the effect of validity was significant in the voluntary attention condition, $F(1, 17) = 31.5, p < .001$; targets in valid-cue trials elicited larger N2 compo-

nents than in invalid-cue trials (-2.43 ± 0.43 vs. $-1.39 \pm 0.47 \mu\text{V}$; Figure 4), but the differences were not significant in the involuntary attention conditions, $F(1, 17) = 3.81, p < .1$ (Figure 5).

For the latency of N2, the main effect of validity was significant, $F(1, 17) = 23.2, p < .001$; compared with valid cue trials N2 latency was later (271.88 ± 2.82 vs. 258.23 ± 2.64 ms) in invalid-cue trials.

P3 Component

SOA had a significant effect on the P3 component, $F(1, 17) = 9.32, p < .01$; targets in the voluntary attention condition elicited larger P3 component amplitudes than in the involuntary attention condition. Validity had a significant effect on P3 amplitude, $F(1, 17) = 8.39, p < .01$. The P3 components were larger in the valid trials than the invalid trials (2.07 ± 0.42 vs. $1.68 \pm 0.38 \mu\text{V}$). The interaction between SOA and validity was significant, $F(1, 17) = 9.35, p < .01$. For further analysis, in the voluntary attention (long SOA) condition, the effect of validity was significant, $F(1, 17) = 20.17, p < .001$; more positive P3 components were elicited by targets in valid-cue trials than in invalid-cue trials (3.72 ± 0.4 vs. $3.04 \pm 0.35 \mu\text{V}$). However, the effect was not significant in the involuntary attention (short SOA) condition, $F(1, 17) = 0.67, p < .5$ (2.42 ± 0.54 vs. $2.32 \pm 0.52 \mu\text{V}$).

Discussion

The present study investigated orienting and focusing in voluntary and involuntary visual-spatial attention conditions and the relationship between these two kinds of attention. Behavioral and ERP data were recorded during a peripherally cued, line-orientation discrimination task designed to result in orienting and focusing. Compared with targets in invalid-cue trials, targets in valid-cue trials enhanced P1 and N1 amplitudes but didn't change their latency in the voluntary attention condition. Larger and later P1 components, and smaller and later N1 components were elicited by the targets in valid-cue trials relative to invalid-cue trials in the involuntary attention condition. The cue size effect had contrary results on P1 components in voluntary and involuntary attention conditions. There was no interaction between orienting and focusing although they were involved in one task. The results of the present study provide behavioral and electrophysiological evidence from one task showing the independence of orienting and focusing of attention and the dissociation between voluntary and involuntary attention.

The Orienting of Visuospatial Attention

The results obtained in this study were consistent with previous behavioral and electrophysiological studies (Doallo

et al., 2004; Fu et al., 2005); faster and more accurate responses were found in valid-cue trials even when the peripheral cue was uninformative.

Cue validity effects on P1 components were observed in both types of attention, which is consistent with a “sensory gain control” mechanism (Doallo et al., 2004; Eimer, 1993; Mangun & Hillyard, 1991). Targets presented on the focus of attention elicited larger contralateral P1 components as the attended point receives preferential perceptual processing. This preferential processing is reflected in facilitation of the visual pathways (Mangun & Hillyard, 1991).

In the voluntary attention condition (long SOA), enhanced N1 components also indicated a cue validity effect that may arise as a result of the discrimination and further orienting of the targets (Mangun & Hillyard, 1991). The P1 and N1 component characteristics found under the voluntary attention condition were consistent with central cueing attention task results (Yamaguchi et al., 1994).

In the involuntary attention condition (short SOA), conflicting results were obtained for the reaction time and latency of P1 components. Faster reaction times were measured in valid cue trials but the P1 component latency was delayed. A previous study by Fu et al. (2005) also observed this conflicting result and proposed different explanations. In the voluntary attention condition, the SOA was long enough to allow participants to control their attention, while in the involuntary attention condition, the SOA was too short for attention control and the cue validity was 50%; since the participants were less likely to avoid the influence of the cue, the cue significantly influenced the target. The delayed P1 component latency may occur because of overlap of the cue with disengage and shift processes for invalid trials. Fu et al. (2005) have previously described this effect and suggested that more attentional resources were used during the early stage of processing, which reflected on the later and larger P1 component, leading to faster reaction times in valid cue trials and faster responses at late stages, because it facilitated the processing at categorization or evaluation for the stimuli. The conflict between P1 latency and reaction time need further testing.

The Focusing of Visuospatial Attention

Compared with small cues, large cues elicited larger P1 and N1 components, and the wave form of the cues suggested that participants paid attention to the cues, they didn't neglect the cues.

In our study, focusing could occur in both the voluntary (long SOA) and involuntary (short SOA) attention conditions. Cue size had a significant effect on the behavioral results. Participants responded moderately faster to targets preceded by small cues than by large cues. However, for the behavior results, the cue size effect was present only in the voluntary attention condition. In the involuntary condition, no significant difference was observed between small- and large-cue trials for behavioral results. However, the averaged response-time data showed that the response time

for the targets in large cue trials was moderately faster than in small-cue trials, which is consistent with results from Fu et al. (2005). Greenwood and Parasuraman (2004) have shown that unpredictable factors result in subjects using a broader attentional focus strategy that favors target discrimination in the large-cue trials. The inapparent cue-size effect in our test may be because we had two frames, covering both the small- and large-cue areas, on the screen throughout the tests to help participants focus their attention, so sensory interactions may have been weakened. These frames enhanced salience of the cues and partly counteracted the negative cue-size effect.

A traditional cue-size effect was found in the voluntary attention condition, where targets in large-cue trials elicited larger P1 components than in small-cue trials. It has been proposed that the lower P1 amplitude elicited by targets in large-cue trials relative to small-cue trials in the involuntary attention condition is because large cues lead to greater adaptation than small cues. This may also be because informative peripheral cues (75% validity) were used and/or the SOA was long enough for a positive cue-size effect. The cue-size effect was observed for ERP results, possibly as a result of greater sensitivity of the ERP technique.

In contrast, in the involuntary attention condition, targets in small-cue trials elicited larger P1 components than in large-cue trials, indicating a negative cue-size effect. In this study, the cue was unpredictable (uninformative peripheral cues) and SOA was short. Participants were unable to predict the cue size and location. If the SOA is too short, a positive cue-size effect will not be observed. Castiello and Umiltà (1990) observed a cue-size effect with SOAs up to 500 ms, but not with 40 ms. Greenwood and Parasuraman (1999, 2004) have shown that voluntary focusing might take longer (more than 100–300 ms) and that the cue-size effect in visual search tasks increases with SOAs from 100 to 500 ms. Fu et al. (2005) have suggested that the onset of a search array automatically attracts participant attention and that the overall configuration of the search array is more important than focusing attention on small, valid cues. Therefore, the strategy used by the participants influences the cue-size effect in the involuntary attention condition. They have also suggested that the negative cue-size effect may be because participants had difficulty maintaining attention on an empty location because they used a blank screen after the cue. In our study, two gray frames were used to help participants maintain attention on the cued location after the cue disappeared. The opposing results can be explained by the amount of attentional effort needed to perform the task. The amplitude of the P1 component could be an indicator of increased attentional effort (Fu et al., 2005) or increased computation (Luo et al., 2001). In the involuntary attention condition, more attentional effort is required for participants to focus their attention on the small cues. Participants need an additional adjustment from the search array (target) for the small cue. Although the cues were uninformative under involuntary attention conditions, there may be an expectation for the cues, because the small cues were more precise.

Larger N1 amplitudes for targets preceded by large-cue trials relative to small-cue trials were found in the involuntary attention condition, and the cue-size effect was not significant on the N1 component in the voluntary attention condition. Luo et al. (2001) found the N1 amplitude decreased as cue size increased in a voluntary attention task. They suggested that a broader attentional focus on a large cue may relate to the decrease of N1 amplitude, and the N1 reflected the gradient of attention allocation. According to our study, we found a contrary result in the involuntary attention condition. We found that the increased N1 amplitude by targets in large-cue trials than in small-cue trials reflected a discrimination process within the focus of attention as Vogel and Luck (2000) suggested in their study, so the N1 amplitude should increase as the response time decreases. Although there was no significant reaction-time result on cue-size effect in the involuntary attention condition in our study, the response time for large-cue trials was a little faster than small-cue trials.

The Relationship Between the Orienting and Focusing

The main effects of both cue validity and cue size were significant in behavioral results. Participants responded faster to valid trials and to small-cue trials. The cue size and cue validity effects had different influences on the early ERP components in different hemispheres, and there was no interaction between the cue size and cue validity. The cue validity effect for the P1 component differed for the contralateral and ipsilateral hemispheres. Valid trials elicited larger contralateral P1 components, reflecting allocation of more attentional resources to facilitate processing at an early stage (Fu et al., 2005). The cue-size effect resulted in similar P1 components in both hemispheres. The difference between the cue validity and cue-size effect suggests that orienting and focusing are two parallel processes with different underlying mechanisms.

The Relationship Between the Voluntary and Involuntary Attention

The attentional effect was reflected in the latency and amplitude of P1, N1, N2 and P3 components, indicating that voluntary and involuntary attention were different from each other. P1 and N1 component latencies were not different for cued and uncued locations during orientation of attention under the voluntary attention condition. However, in the involuntary condition, P1 and N1 component latencies were different for cued and uncued locations. The amplitudes of P1 and N1 components were also different between the voluntary and involuntary attention conditions. The N1 component amplitude was enhanced by valid trials relative to invalid trials in the voluntary attention condition,

in agreement with previous ERP studies. Smaller and later N1 components were elicited by targets in valid trials than in invalid trials in the contralateral temporal area in the involuntary attention condition. The reduction of N1 components appears to be a consequence of the overlapping positivity from the enhancement of the late P1 wave.

The results for N2 components also showed differences between voluntary and involuntary attention. SOA and validity interactions had a significant effect on N2 components while the cue validity effect was only significant in the voluntary attention condition. No clear N2 component was observed in the involuntary attention condition (Figure 5). According to Luck and Hillyard (1994), N2 components reflect the capability of inhibiting distraction. In some previous temporal attention studies (Correa, Lupiáñez, & Tudela, 2005; Miniussi, Wilding, Coull, & Nobre, 1999), invalid or conflicting stimuli elicited a more negative N2 component. In our spatial attention task, we found a less negative N2 component in invalid trials than in valid trials. A similar result was also observed by Mangun et al. (1993). In the spatial attention task, the N2 component was a sign of executive processes to direct attention in space.

P3 component amplitudes are larger when subjects exert more effort. Hopfinger and West (2006) have shown that when voluntary and involuntary attention are both activated, voluntary attention controls the late stage of processing; compared with invalid trials, targets in valid cue trials elicited larger P3 components in the voluntary attention condition. In our study, the cue validity effect was more active in the voluntary attention condition. This result may reflect a decision-making process requiring more effort in the voluntary attention condition. As we mentioned before, P3 components may reflected a dissociation of the voluntary and involuntary attention (Anllo-Vento, 1995; Hillyard et al., 1994; Hopfinger & Mangun, 1998; Hopfinger & West, 2006). With informative peripheral cues on long cue-to-target SOAs tasks (Anllo-Vento, 1995; Hillyard et al., 1994) the P3 amplitudes were larger in invalid trials relative to valid trials, but with uninformative peripheral cueing on short SOAs tasks (Hopfinger & Mangun, 1998), larger P3 amplitudes were found in valid trials than in invalid trials.

In the involuntary attention condition, focusing of attention resulted in larger P1 components elicited by targets in small-cue trials in both hemispheres. In the voluntary attention condition, larger P1 components were elicited by targets in large-cue trials in both hemispheres. The difference between voluntary and involuntary attention in our experiment indicates that the peripheral cueing task can be used to elicit both kinds of attention and that both attention types can occur during one task. These attentional processes involve distinct underlying neural mechanisms and they involve, at least partially, independent resource pools.

In summary, the present findings indicate that orienting and focusing of visual-spatial attention are deployed independently in both voluntary and involuntary attention conditions. Furthermore, voluntary and involuntary attentions were shown to be dissociated within one task.

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References

- Anllo-Vento, L. (1995). Shifting attention in visual space: The effects of peripheral cueing on brain cortical potentials. *International Journal of Neuroscience*, *80*, 353–370.
- Berger, A., Henik, A., & Rafal, R. (2005). Competition between endogenous and exogenous orienting of visual attention. *Journal of Experimental Psychology General*, *134*, 207–221.
- Castiello, U., & Umiltà, C. (1990). Size of the attentional focus and efficiency of procession. *Acta Psychologica*, *73*, 195–209.
- Cheal, M., & Lyon, D. R. (1991). Central and peripheral precueing of forced-choice discrimination. *Quarterly Journal of Experimental Psychology, A* *43*, 859–880.
- Clark, V. P., Fan, S., & Hillyard, S. A. (1995). Identification of early visual evoked potential generators by retinotopic and topographic analyses. *Human Brain Mapping*, *2*, 170–187.
- Clark, V. P., & Hillyard, S. A. (1996). Spatial selective attention affects early extrastriate but not striate components of the visual evoked potential. *Journal of Cognitive Neuroscience*, *8*, 387–402.
- Correa, Á., Lupiáñez, J., Madrid, E., & Tudela, P. (2006). Temporal attention enhances early visual procession: A review and new evidence from event-related potentials. *Brain Research*, *1076*, 116–128.
- Correa, Á., Lupiáñez, J., & Tudela, P. (2005). Attentional preparation based on temporal expectancy modulates processing at the perceptual level. *Psychonomic Bulletin and Review*, *12*, 328–334.
- Doallo, S., Lorenzo-Lopez, L., Vizoso, C., Rodriguez, H. S., Amedo, E., Bara, S., & Cadaveira, F. (2004). The time course of the effects of central and peripheral cues on visual processing: An event-related potentials study. *Clinical Neurophysiology*, *115*, 199–210.
- Eimer, M. (1993). Spatial cueing, sensory gating, and selective response preparation: An ERP study on visuospatial orienting. *Electroencephalography and Clinical Neurophysiology*, *88*, 408–420.
- Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception and Psychophysics*, *40*, 225–240.
- Eriksen, C. W., & Yeh, Y. Y. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance*, *11*, 583–597.
- Fu, S., Caggiano, D. M., Greenwood, P. M., & Parasuraman, R. (2005). Event-related potentials reveal dissociable mechanisms for orienting and focusing visuospatial attention. *Cognitive Brain Research*, *23*, 341–353.
- Fu, S., Fan, S., Chen, L., & Zhuo, Y. (2001). The attentional effects of peripheral cueing as revealed by two event-related potential studies. *Clinical Neurophysiology*, *112*, 172–185.
- Fu, S., Zinni, M., Squire, P. N., Kumar, R., Caggiano, D. M., & Parasuraman, R. (2008). When and where perceptual load interacts with voluntary visuospatial attention: An event-related potential and dipole modeling study. *NeuroImage*, *39*, 1345–1355.
- Gowen, E., Abadi, R. V., Poliakoff, E., Hansen, P. C., & Miall, R. C. (2007). Modulation of saccadic intrusions by exogenous and endogenous attention. *Brain Research*, *1141*, 154–167.
- Greenwood, P. M., & Parasuraman, R. (1999). Scale of attentional focus in visual search. *Perception and Psychophysics*, *61*, 837–859.
- Greenwood, P. M., & Parasuraman, R. (2004). The scaling of spatial attention in visual search and its modification in healthy aging. *Perception and Psychophysics*, *66*, 3–22.
- Griffin, I. C., Miniussi, C., & Nobre, A. C. (2002). Multiple mechanisms of selective attention: Differential modulation of stimulus processing by attention to space or time. *Neuropsychologia*, *40*, 2325–2340.
- Hawkins, H. L., Hillyard, S. A., Luck, S. J., Mouloua, M., & Downing, C. J. (1990). Visual attention modulates signal detectability. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 802–811.
- Hillyard, S. A., Luck, S. J., & Mangun, G. R. (1994). The cuing of attention to visual field locations: Analysis with ERP recordings. In H. J. Heinze, T. F. Münte, & G. R. Mangun (Eds.), *Cognitive electrophysiology: Event-related brain potentials in basic and clinical research* (pp. 1–25). Boston, MA: Birkhäuser.
- Hopfinger, J. B., & Mangun, G. R. (1998). Reflexive attention modulates processing of visual stimuli in human extrastriate cortex. *Psychological Science*, *9*, 441–447.
- Hopfinger, J. B., & West, V. M. (2006). Interactions between endogenous and exogenous attention on cortical visual processing. *NeuroImage*, *31*, 774–789.
- Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. In J. B. Long & A. D. Baddeley (Eds.), *Attention and performance IX* (pp. 187–203). Hillsdale, NJ: Erlbaum.
- Luck, S. J., & Hillyard, S. A. (1994). Electrophysiological correlates of feature analysis during visual search. *Psychophysiology*, *31*, 291–308.
- Luo, Y. J., Greenwood, P. M., & Parasuraman, R. (2001). Dynamics of the spatial scale of visual attention revealed by brain event-related potentials. *Cognitive Brain Research*, *12*, 371–381.
- Mangun, G. R. (1995). Neural mechanism of visual selective attention. *Psychophysiology*, *32*, 4–18.
- Mangun, G. R., & Hillyard, S. A. (1990). Electrophysiological studies of visual selective attention in humans. In A. B. Scheibel & A. F. Wechsler (Eds.), *Neurobiology of higher cognitive function* (pp. 271–295). New York: Guilford.
- Mangun, G. R., & Hillyard, S. A. (1991). Modulations of sensory-evoked brain potentials indicate changes in perceptual processing during visual-spatial priming. *Journal of Experimental Psychology: Human Perception and Performance*, *17*, 1057–1074.
- Mangun, G. R., Hillyard, S. A., & Luck, S. J. (1993). Electrocortical substrates of visual selective attention. In D. Meyer & S. Kornblum (Eds.), *Attention and performance XIV* (pp. 219–243). Cambridge, MA: MIT.
- Miniussi, C., Wilding, E., Coull, J., & Nobre, A. (1999). Orienting attention in time: Modulation of brain potentials. *Brain*, *122*, 1507–1518.
- Müller, H. J. (1994). Qualitative differences in response bias from spatial cueing. *Canadian Journal of Experimental Psychology*, *48*, 218–241.
- Müller, H. J., & Rabbitt, P. M. (1989). Reflexive and voluntary

- orienting of visual attention: Time course of activation and resistance to interruption. *Journal of Experimental Psychology: Human Perception and Performance*, 15, 315–330.
- Posner, M.I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, 32, 3–25.
- Posner, M.I., & Cohen, Y. (1984). Components of visual orienting. In H. Bouma & D. G. Bouwhuis (Eds.), *Attention and performance X: Control of language processes* (pp. 531–556). Hillsdale, NJ: Erlbaum.
- Riggio, L., & Kirsner, K. (1997). The relationship between central cues and peripheral cues in covert visual orientation. *Perception and Psychophysics*, 59, 885–899.
- Semlitsch, H. V., Anderer, P., Schuster, P., & Presslich, O. (1986). A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology*, 23, 695–703.
- Turatto, M., Benso, F., Facoetti, A., Galfano, G., Mascetti, G. G., & Umiltà, C. (2000). Automatic and voluntary focusing of attention. *Perception and Psychophysics*, 62, 935–952.
- Vogel, E. K., & Luck, S.J. (2000). The visual N1 component as an index of a discrimination process. *Psychophysiology*, 37, 190–203.
- Woldorff, M. G. (1993). Distortion of ERP averages due to overlap from temporally adjacent ERPs: Analysis and correction. *Psychophysiology*, 30, 98–119.
- Yamaguchi, S., Tsuchiya, H., & Kobayashi, S. (1994). Electroencephalographic activity associated with shifts of visuospatial attention. *Brain*, 117, 553–562.

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