# Brain dynamic mechanisms of scale effect in visual spatial attention

Wei-qun Song[a], Xinying Li[b], Yue-Jia Luo[c], Bo-qi Du[c] and Xun-ming Ji[a]

[a]Department of Rehabilitation, Xuanwu Hospital, Capital University of Medical Science, [b]Key Laboratory of Mental Health, Institute of Psychology, Chinese Academy of Sciences and [c]State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing, China

Correspondence and requests for reprints to Dr Yue-Jia Luo, 19 Xinjiekouwaidajie, Beijing 100875, P.R. China
Tel: +86 10 5880 2365; fax: +86 10 5880 2365; e-mail: luoyj@bnu.edu.cn

Sponsorship: This work was supported by the National Nature Science Foundation of China (Grant no. 30540058, 30325026, 30370489, 30500166), the Capital Nature Science Foundation (Grant no. 7052030), the Capital Excellence Foundation, the key Research Program of the Chinese Academy of Science (Grant no. 30325026) and the Key Research Program of the National Science Technical Ministry (Grant no. 2002CCA0100).

Received 3 July 2006; accepted 7 July 2006

The dynamic mechanisms of the early event-related potential scale effect of different attentive regions in the brain was studied. The paradigm of this experiment is the precue-target visual search paradigm by event-related potential technique. The results showed that the reaction time was shortened with the reduction of cue scale, a cue to how big the search area would be, and fixed target stimulus, while the amplitudes of P1 and N1 components of event-related potentials increased. These results not only provided the electrophysiological evidences that supported the zoom-lens theory, but also indicated that the zoom-lens effect happened at the early selected attention period. The results also showed that there existed two kinds of separation in the P2 effect. *NeuroReport* 17:1643–1647 © 2006 Lippincott Williams & Wilkins.

**Keywords**: event-related potential, scale effect, visual spatial attention

## Introduction

Visual spatial attention (VSA) can focus the individual's attention on the local area in order to selectively process the stimuli in this area. VSA can effectively select the information within the visual area through the participant's voluntary orientation. This kind of attention mode is called the 'spotlight effect' by the American psychologist Posner [1]. Eriksen and Stjames [2] put forward and developed the 'zoom-lens' model on spatial attention. The difference between the two models mainly lies in that the effective region in the zoom-lens model can be adjusted, whereas the 'spotlight' is fixed. The zoom-lens model holds that spatial attention is a system with limited resources, which can be directed to a certain spatial region with a fixed size. Enlarging the spatial attention region enables the attentive resources to be distributed in an even larger region. Therefore, with the decrease in the identification at any given location in the attentive region, the enlargement of attentive region can reduce the density of processing resources in this region.

In cognitive neuroscience research on spatial attention, the selective attention evoked the increase of amplitude of the P1 and N1 components of event-related potential (ERP), and the P1 component at the bilateral–occipital region represented the earliest period of the visual process regulated by spatial attention. The time ranges of posterior P1 and N1 are 50–160 and 161–220 ms, respectively. The time range of anterior N1 is 90–180 ms. The results of brain imaging of the P1 component showed that the scalp distribution of the P1 component was mainly located at the extrastriate cortical areas [3]. Luo *et al.* [4,5] used the 'cue-target stimulus' mode for the investigation, that is, cues' information related to location was presented before the target stimuli appeared and these cues directed attention to a region in space. The spatial scale where the target would appear was divided into three levels: large, medium and small. The participants were asked to voluntarily direct their attention to some location and the visual search began.

The results showed that the larger the spatial scale, the larger the amplitude of the P1 evoked. As the location of the cue used in the Luo *et al.* [4,5] study was at random, this could have affected the scale effect of the cue. This study focused on the difference in components of ERP, evoked by the targets located in the specified area, which had fixed field cues. The conclusion has shed light on the visual selection mechanism of the brain in VSA. Besides the P1 and N1 components, we examined the P2 component, which occurs from 180 to 270 ms after the stimulus. The P2 component is generally thought to reflect the evaluation of the targets.

## Methods

### Subjects

Eighteen healthy young participants (nine men and nine women, 19–24 years old with an average of 21 years old) were paid for participating in the experiment. They were all right-handed, and had normal or corrected-to-normal visual acuity. Two of them were ruled out because they blinked too often in the process of electroencephalogram (EEG). Therefore, 16 of them were used for statistical analysis.

### Stimulus material

The stimulation was presented on the screen. A trial included 'background-cue-target'. The background was composed of three homocentric white circles. The stimulation material was capital English characters, which also formed three homocentric circles. In all, there were eight characters in each circle; 'T' was designated as the target stimulus. The distance between two adjacent characters in the same circle was identical. The eight characters of each circle were divided into right and left visual fields by the vertical bisector on the screen. The visual angles of large, medium and small circles were 8.6, 5.7 and 2.9°, respectively. All of the characters were white and the background was black. A white point at the center of the screen was the attention point. The cue was composed of three Chinese characters '小' or '中' or '大' (meaning large or medium or small). When the cue was large, the target 'T' might have appeared in any of the three circles; when the cue was medium, the target 'T' might appear within the medium and small circles; when the cue was small, the target 'T' might appear only within the small circle. The stimuli appeared within each circle with equal probability.

The stimulation was presented in the sequence shown in Figure 1. (a) The background is composed of three circles. (b) The cue is the Chinese character '小', '中', or '大'. (c) The 'T' designated as the target could appear in any of the circles of capital letters.

### Event-related potential recording

The EEG was recorded from 64 scalp sites using tin electrodes mounted on an elastic cap (NeuroScan ERP workstation), with the reference on the left and right mastoids. The vertical electrooculogram (EOG) was recorded with electrodes placed above and below the left eye. All interelectrode impedance was maintained below 5 kΩ. The EEG and EOG were amplified using a 0.1–40 Hz bandpass and continuously sampled at 500 Hz/channel for offline analysis. ERPs were averaged over a 500-ms epoch including a 100-ms prestimulus baseline. Trials with EOG artifacts (mean EOG voltage exceeding $\pm 100\,\mu V$) were excluded from the average.

### Procedure and task

First, the background was presented for 300 ms. Then, the cue was presented for 300 ms. Finally, the target stimulus – three circles composed of 24 characters – was presented for 1500 ms. The interval between the cue and stimuli was 400–600 ms randomly. The task of the participants was to search for the target character 'T' within the effect region appearing in the left or right visual field according to the cues. If 'T' appears in the left (right) visual field, the participant has to press the left (right) button. The goals for participants were to be both correct and quick. The character 'T' appeared in the left or right visual field equally (45% chance each). In 10% of the trials, target was not present.

### Event-related potential data analysis and statistics

The overlap of early ERP component between cue scale and target stimuli under short interval condition was eliminated using the Adjar method. The three kinds of cues evoked differing ERP components. The number of trials in which components overlapped for each participant ranged from 45 to 68 times, with an average of 55 times. The following 14 sites were chosen for statistical analysis: POZ, PO3, PO4, PO5, PO6, PO7, PO8 (seven sites for posterior) and Fz, F1, F2, F3, F4, F5, F6 (seven sites for anterior). Cue-evoked ERP were analyzed at the posterior scalp for 50–160 ms (P1), 161–220 ms (N1), 221–290 ms (P2), 291–390 ms (N2). Cue-evoked ERP were analyzed at the anterior scalp in 90–180ms (N1), 181–270 ms (P2), 271–370 ms (N2). The descriptive data are presented as mean ± SE. The latencies and amplitudes of the above ERP components were analyzed by three-way repeated-measures analyses of variance (ANOVA). The ANOVA factors were cue size (three levels: large, medium and small) and electrode sites (seven sites each for anterior and posterior components). The $P$ values of ANOVA were calculated using the Greenhouse–Geisser method.

## Results

### Behavior data

The main effects of different cues were significant ($F_{2,30} = 7.26$, $P < 0.005$). These results suggested that the larger the cue scale, the longer the response time of the participants. The average response time for small, medium and large cues were 590.8, 634.7 and 635.8 ms, respectively. The difference in response time to the left and right visual fields was also significant ($F_{1,15} = 17.96$, $P < 0.001$). The response time for the left visual field was 646.9 ms, whereas the response time for the right visual field was 594.90 ms. All of the participants were more than 90% correct.

### Cue effects of different scale

The amplitudes and latencies of the ERP components are shown in Table 1. As shown in Fig. 2, there were significant main effects in the posterior scalp P1 amplitude ($F_{2,30} = 14.33$, $P < 0.001$); the P1 amplitudes of small cues ($4.0 \pm 5.6\,\mu V$) were larger than those of medium ($2.1 \pm 0.53\,\mu V$) and large ($2.2 \pm 0.58\,\mu V$) cues. There were no main effects of P1 latency. No significant interaction was found for any condition.

**Table 1** Maximum amplitudes and latent periods of all the event-related potential (ERP) components with fixed target stimuli

| ERP components | Cue in the small region | | Cue in the medium region | | Cue in the large region | |
|---|---|---|---|---|---|---|
| | Amplitude | Latent period | Amplitude | Latent period | Amplitude | Latent period |
| Anterior N1 | −2.43 ± 0.21 | 98 ± 11.3 | −1.46 ± 0.20 | 110 ± 9.8 | −1.41 ± 0.30 | 108 ± 10.6 |
| Anterior P2 | 2.98 ± 0.30 | 120 ± 14.7 | 3.03 ± 0.29 | 126 ± 11.3 | 3.62 ± 0.33 | 128 ± 11.5 |
| Posterior P1 | 2.48 ± 0.20 | 106 ± 23.5 | 1.24 ± 0.16 | 108 ± 15.4 | 1.23 ± 0.23 | 109 ± 13.6 |
| Posterior N1 | −2.63 ± 0.32 | 153 ± 21.3 | −2.84 ± 0.30 | 155 ± 13.2 | −3.05 ± 0.40 | 154 ± 14.7 |

A significant main effects exist in the anterior N1 amplitude ($F_{2,30}=11.50$, $P<0.01$). Small cues evoked large N1 amplitude ($-2.0\pm0.5\,\mu V$), the medium cues ($0.9\pm0.4\,\mu V$) and large cues ($0.9\pm0.3\,\mu V$) evoked the smaller amplitude. No significant cue effect exists in anterior N1 latency. Furthermore, there was no cue effect in the posterior N1 component.

Significant scale effect was found in the anterior P2 amplitude ($F_{2,30}=8.22$, $P<0.01$). The P2 amplitudes of small, medium and large cues were $2.99\pm0.91$, $3.8\pm0.44$ and $4.5\pm0.39\,\mu V$, respectively. The main effect of electrode sites was significant ($F_{6,90}=14.68$, $P<0.0001$; ($F_{12,180}=4.34$, $P<0.003$).

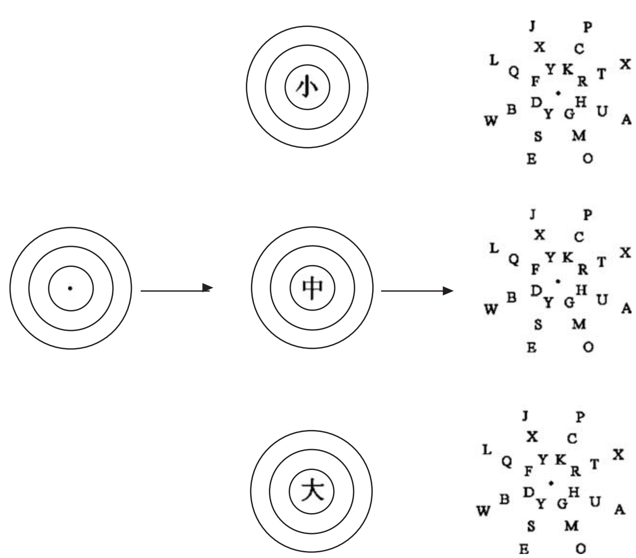


**Fig. 1** Sketch map of the experimental model. The stimulation is presented in the sequence shown: (a) the background, composed of three circles, is shown first. (b) The cue is the Chinese character '小', '中', or '大'. (c) 'T', the designated target, can appear in any of the three circles, which are comprised of capital letters.

**Hemispheric differences**

A more significant scale effect for the posterior P1 component is found in the left hemisphere than in the right hemisphere. The data for the left hemisphere were PO3 $F_{2,30}=14.26$, $P<0.001$ and PO5 $F_{2,30}=11.73$, $P<0.001$, whereas for the right hemisphere they were PO4 $F_{2,30}=4.18$, $P<0.05$ and PO6 $F_{2,30}=4.84$, $P>0.05$.

As depicted in Fig. 3, the anterior P2 component in the left hemisphere had the same scale effect. Scale main effect was significant in the left hemisphere ($F_{2,30}=16.74$, $P<0.001$), whereas there were no significant differences in the right hemisphere.

**Analysis of dipole resource**

In order to estimate the brain location of the hemisphere predominance, dipoles based on the three concentric shell model were analyzed with Curry software at each time point from 60 to 280 ms. Results are shown in Fig. 4. At each time point in the 80–160 ms latency range, a reasonable solution could be obtained, with residual variances ranging from a maximum of 15.9% at 80 ms to a minimum of 7.01% at 160 ms. At all time points in this latency range, the dipoles were located in occipital brain areas (left: $x=-29.5$, $y=-86.4$, $z=-15.2$; right: $x=12.4$, $y=-87.3$, $z=-14.1$). The other two dipoles, which were fixed in the symmetrical locations to each other, were localized in parietal brain areas (left: $x=-37.5$, $y=25.5$, $z=-65.9$; right: $x=-30.2$, $y=-61.4$, $z=43.7$), with residual variances ranging from a maximum of 18.9% at 184 ms to a minimum of 8.83% at 210 ms. These results supported the idea that the P1 was located at the

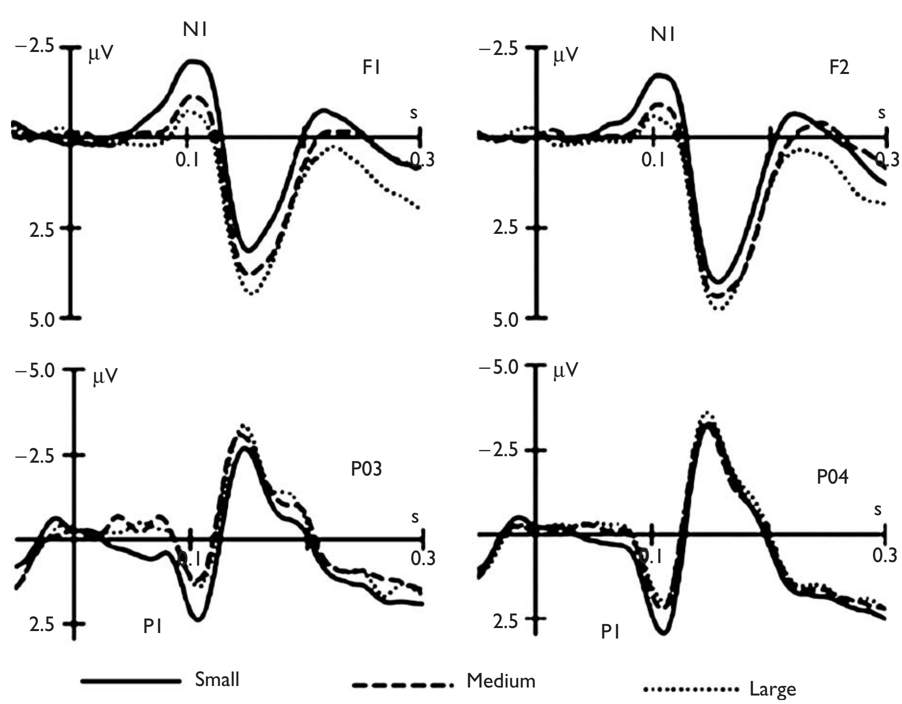


**Fig. 2** The waveforms of grand averaged amplitudes of N1 (anterior) (upper) and P1 (posterior) (lower) for each cue region.

occipital region and the P2 was located at the parietal brain areas and the spatial attention finished mainly through the 'Where' pathway.

## Discussion

The experiment showed that the response time was shortened gradually with the reduction of cue scale (large → medium → small); whereas the amplitude values of P1 and N1 evoked by small cues were significantly larger than those evoked by medium and large cues. Results showed that response time became longer with increasing size of cue regions. The behavioral and electrophysiological findings not only effectively supported the zoom-lens theory of spatial attention but also made it clear that the zoom-lens effect of attention occurred in the early period of information processing, which accords with the early-processed theory.

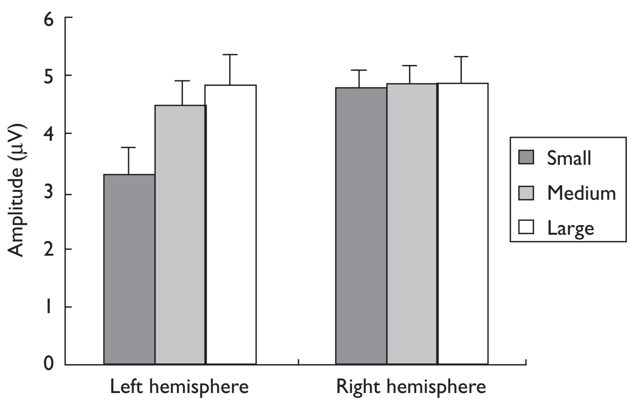


**Fig. 3** Comparison of hemisphere superiority on P2 under different cue regions.

The experiment also found that the P2 amplitude in the anterior of the right hemisphere was much higher than that in the corresponding left area, no matter what visual stimulus appeared in the left or right visual field. It also showed that the right hemisphere functioned more actively when the participants did the search task. The hemispheric difference occurred at the late period of information processing. In neuropsychological research, patients with brain damage in the right parietal region have shown spatial attention defect, whereas this phenomenon did not occur in patients with brain damage in the left parietal region [6]. Generally, the right hemisphere predominated in spatial attention. In this study, we found the P1 and P2 components in the left hemisphere had significant scale effect. The P1 amplitude decreased with the increase of cue scale, whereas the P2 amplitude increased with the increase of cue scale. In all there were two kinds of separation in P2 effect. One was the separation between P1 effect and P2 effect, which showed that the spotlight effect happened in the early selected attention period; the enlargement of attentive region at the late period needed additional computation. The other separation was between the left and right parts of the P2 effect. The P2 amplitude in the right hemisphere generally increased with increasing cue size, but a much stronger scale effect happened in the left hemisphere. This result showed that the attention process related to the cued region existed in the left hemisphere, which supported the traditional idea that the right hemisphere predominated in VSA.

## Conclusion

The experiment not only effectively supported the zoom-lens theory of spatial attention, but also made it clear that

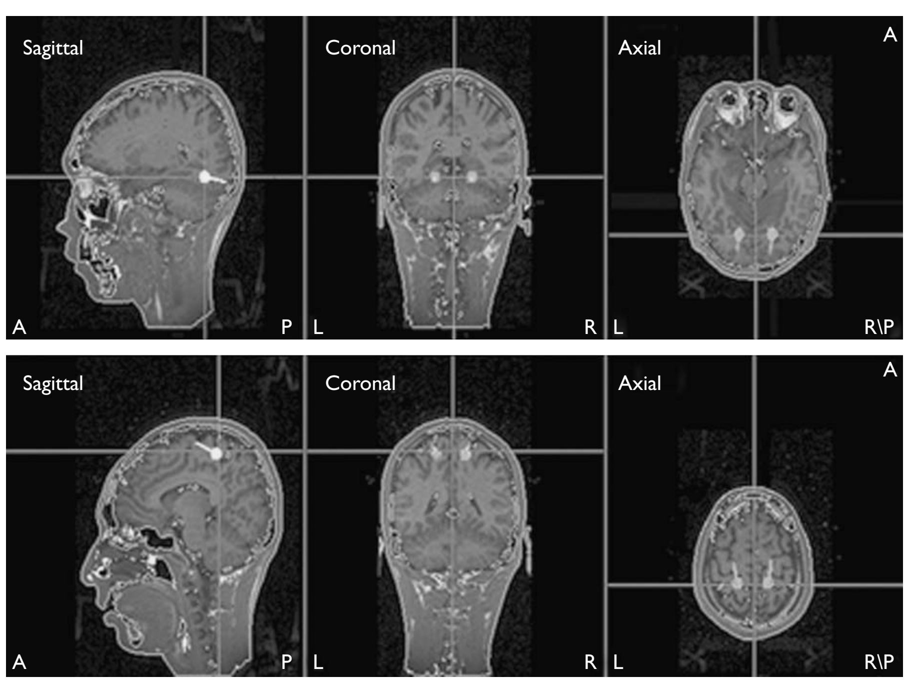


**Fig. 4** The location of dipole after stimulation, shown from the sagittal, coronal and axial angles. The dipoles were focused in the occipital and parietal brain areas.

the zoom-lens effect of attention occurred in the early period of information processing, which accorded with the early-processed theory. In this study, we found the P1 and P2 components in the left hemisphere had significant scale effects. The P1 amplitude decreased with the increase of cue scale, whereas the P2 amplitude increased with the increase of cue scale. The two kinds of separation in P2 effect augmented the traditional idea that the right hemisphere predominates in VSA.

## Acknowledgement
The author would like to thank Professor Wei Jing-han for his valuable advice on the research.

## References

1. Posner MI. Orienting of attention. *Exp Psychol* 1980; **32**:3–25.
2. Eriksen CW, Stjames JD. Visual attention within and around the field of focal attention: a zoom lens model. *Percept Psychophys* 1986; **40**: 225–240.
3. Ungerleider LG, Haxby J. 'What' and 'where' in the human brain. *Curr Opin Neurobiol* 1994; **4**:157–165.
4. Luo YJ, Greenwood PM, Parasuraman R. Dynamics of the spatial scale of visual attention revealed by brain event-related potentials. *Brain Res Cogn Brain Res* 2001; **12**:371–381.
5. Luo YJ, Parasuraman R. The early ERP effects neural activity in spatial scale of visual attention. *Acta Psychol Sinica* 2001; **33**:385.
6. Barthelemy S, Boulingnez P. Orienting visuospatial attention generates manual reaction time asymmetries in target detection and pointing. *Behav Brain Res* 2002; **133**:109–127.