Early scale effect and hemisphere superiority on the visual spatial attention: From the electrophysiological evidence of ERP*

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Abstract The visual attention mechanism in the brain was studied among 16 young subjects through the precue-target visual search paradigm using the event-related potentials (ERPs) technique, with the attentive ranges cued with different scales of Chinese words. The results showed that the response time was shortened as the cue scale was reduced, while the amplitudes of the P1 and N1 components of the ERPs increased. These results not only provided the electrophysiological evidence supporting the spotlight theory, but also indicated that the spotlight effect occurred during the early period of the selected attention. Two kinds of separation in the P2 effect were observed. One separation was between the P1 effect and P2 effect, which meant that additional computation was needed when the spatial scale of attention was enlarged; the other was between the left and right hemisphere of the P2 effect, which indicates that the attentive processing of the cue range mainly occurred in the left hemisphere.

Keywords: visual spatial attention, cue scale, spotlight effect, hemisphere superiority, event-related potential (ERP).

When there are multiple visual stimuli, the visual spatial attention helps focus an individual's attention on a more local area in order to selectively process stimuli of interest. Without requiring head or eye movement, visual spatial attention can effectively select the information within the visual area through the subject's voluntary orientation. This kind of attention mode is called "spotlight effect"[1]. The selected stimuli will enter the range of the "spotlight" and be processed more quickly and more effectively, while the stimuli outside the "spotlight" range is ignored.

Ungerleider et al.[2] reported that there are two pathways in the brain to process vision: The first is known as the "what" pathway, which runs through the ventral stream in the brain from the occipital lobe - the visual cortex - to the inferior temporal cortex. Its function is to recognize external objects and form the perception of the objects. The second pathway is known as the "where" pathway, which runs through the dorsal stream to the posterior parietal cortex, and its function is related to determining the spatial location and motion perception of the objects.

In the cognitive neuroscience research conducted on spatial attention, selective attention evoked increased amplitude of the P1 and N1 components of ERP, and the P1 component at the bilateral-occipital region represented the earliest period of visual process regulated by the spatial attention. The results of the brain imaging of the P1 component showed that the scalp distribution of the P1 was mainly located at the extrastriate cortical areas. Luo et al.[4,5] used the "cue-target stimulus" mode to investigate visual spatial attention, i.e. cues information related with location was presented before the target stimuli appeared, and the spatial scale where the target would appear was divided into three levels —"large, medium and small." The subjects were asked to consciously direct their attention to a particular location and begin the visual search. They recorded the ERP components evoked by the cue and target. The results showed that larger spatial scales evoked larger P1 amplitudes. Researchers concluded that enlargement of the scale reflected the up-down control and processing mechanisms related to the visual search range. However, the spatial location of the cue used in the study was selected at random, and affected the scale effect of the cue accordingly. In this regard, the experimental mode was improved. The fixed orientation cues[6] and Chinese character cues[7] were used to rule out the effect of spatial location factors. The results showed

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that the attention was not reflected in the early P1 and N1 components, but reflected in the later components, such as P2 and N2. Making this improvement erased the disturbance of the location movement, but because the cue was fixed in the center of the circle and the differentiation between the target scales was not significant, the subjects were able to make a judgment ignoring the cue, thereby affecting the validity of the cues. Based on the above consideration, we used three different circles comprised of English characters such that the target could appear in any range. The cue intensity and the recognized difficulty of the target stimuli increased. At the same time, we analyzed the source of the dipoles. The purpose of the present study is to investigate the spatial-temporal integrity mechanism, which was related to the spatial attention scale effect, and to try to find any evidence supporting spotlight theory.

1 Methods

1.1 Subjects

Of the 16 healthy young participants (eight males and eight females, 19～24 years old with an average age of 21 years) were selected to attend the electrophysiological experiment for the first time. The subjects are all right-handed, and have normal and corrected visual acuity.

1.2 Stimuli

Stimuli were located on computer screens. Each stimuli trail included "background-cue-target masks". The background was comprised of three homocentric black circles. The stimulus material comprised of a capital English letter, forming three homocentric circles. Each circle contained eight letters; "T" was designed as the target stimulus. Eight letters were divided into the left and right visual field (LVF/RVF) by the vertical bisector in the screen. The visual angles of the large, medium and small scales were 8.6°, 5.7°, and 2.9° respectively. All of the letters were displayed in black with a white background. A black point at the center of the screen was the focul point. The precue consisted of three Chinese characters "large", "medium" or "small" (meaning large or medium or small), see Fig. 1. When the cue was large, the target "T" appeared within either of the three circles; when the cue was medium in size, the target "T" appeared either within the medium or small circle; when the cue was small, the target "T" appeared only within the small circle.

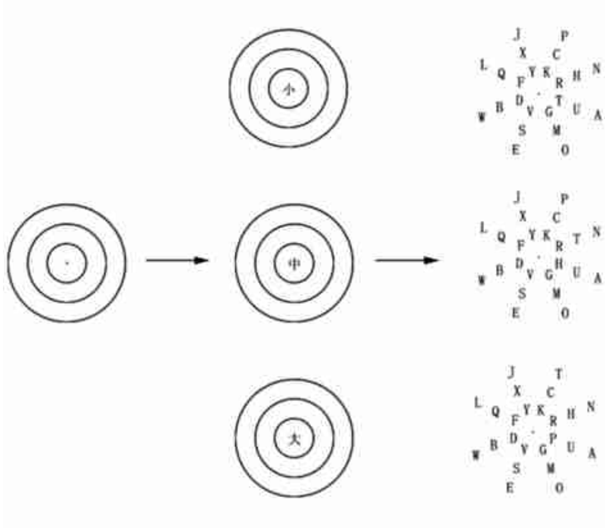

Fig. 1. Sketch map of the experimental model.

1.3 Event-related potential (ERP) recording

The electroencephalogram (EEG) was recorded from 64 scalp sites using an electrode cap (Neurosoft Co. USA), with references on the left and right mastoids. The vertical electrooculogram (EOG) was recorded with electrodes placed above and below the left eye. All inter-electrode 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 off-line analysis. ERPs were averaged over a 500 ms epoch including a 100 ms prestimulus baseline. Trials with EOG artifacts (mean EOG voltage exceeding ±100 μV) were excluded from averaging.

1.4 Procedure and task

The background was presented, at first, for 300 ms, followed by 300 ms of the cue. The target stimuli were then presented for 1500 ms. The interval between the cue and stimuli was set at 400～600 ms at random. Subjects were asked to search for the target "T" within the effect range appearing either on the LRF/RVF according to the cues. If the "T" appeared in the LRF or RVF, subjects were asked to press the left or right buttons accordingly as quickly as possible. There was equal probability of the "T" appearing in the LVF/RVF, and 10% of the stimuli lacked target stimuli.

1.5 ERP data analysis and statistics

The overlap of the early ERP component between the cue scale and target stimuli under short interval conditions was eliminated using the Adjar method[8]. Three kinds of cues evoked the respective ERP components. The components evoked by the targets in the smallest circle were analysis. The overlapping times ranged from 45 to 68 times with an average of 55 times. In accordance with the purpose and wave feature of general average figure, the following 14 sites were chosen for statistical analysis: POZ, PO3, PO4, PO5, PO6, PO7, PO8 (7 sites from posterior) and Fz, F1, F2, F3, F4, F5, F6 (7 sites from anterior). The time windows of the ERP component were analyzed at the posterior scalp in 50～160 ms (P1), 161～220 ms (N1), 221～290 ms (P2), and 291～390 ms (N2) intervals. For the anterior scalp, they were analyzed for 90～180 ms (N1), 181～270 ms (P2), 271～370 ms (N2) intervals. The descriptive data were 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 (3 levels: large, medium and small) and electrode sites (7 sites each for the anterior and posterior components respectively). The P values of the ANOVA were corrected using the Greenhouse-Geisser method.

2 Results

2.1 Behavior data

The main effect of different cues was significant ($F_{2,30} = 7.26$, $P < 0.005$), which suggested that the larger the cue scale, the longer the response of the subjects. The reaction time (RT) of the small, medium and large cues were 590.8, 634.7, 635.8 ms respectively. The RT to the left and right visual field was also significant ($F_{1,15} = 17.96$, $P < 0.001$). The RT of the left visual field was 646.9 ms, while the response time of right visual field was 594.9 ms. All of the correct ratios were higher than 90 %.

2.2 Cue effects of different scale

At the posterior scalp, the main effect of the P1 amplitude was significant ($F_{2,30} = 14.33$, $P < 0.001$); the P1 amplitude to the small cue (4.0 ± 5.6 μV) was larger than those of the medium (2.1 ± 0.53 μV) and the large cues (2.2 ± 0.58 μV). The main effect of the P1 latency was not significant. There was no significant interaction under all conditions.

In the anterior, the main effect of the N1 amplitude was significant ($F_{2,30} = 11.50$, $P < 0.01$). The N1 amplitude elicited by the small cue was larger (-2.0 ± 0.5 μV) than those by the medium cue (-0.9 ± 0.4 μV) and large cue (-0.9 ± 0.3 μV). There was no significant cue effect in the anterior N1 latency. Furthermore, there was no cue effect in the posterior N1 component (Fig. 2).

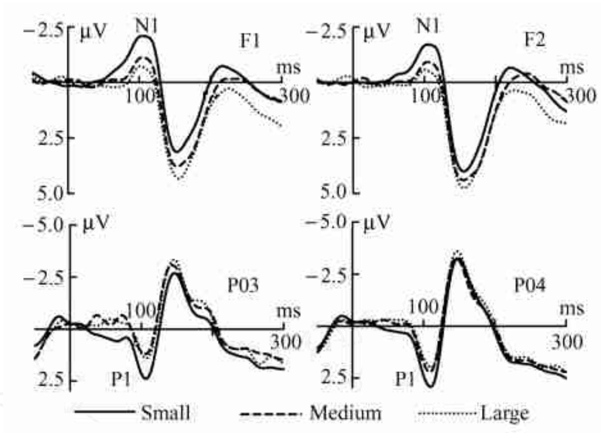

Fig. 2. The wave feature of general average figure of anterior N1 (upper) and posterior P1 (lower).

There was significant scale effect in the anterior P2 amplitude ($F_{2,30} = 8.22$, $P < 0.01$). The P2 amplitudes to the small, medium and large cues were 2.99 ± 0.91, 3.8 ± 0.44, 4.5 ± 0.39 μV respectively. The main effect of electrode sites was significant ($F_{12,180} = 4.34$, $P < 0.003$).

2.3 Hemisphere superiority

There was more significant scale effect of the posterior P1 component in the left hemisphere than in the right hemisphere, for example, $F_{2,30} = 14.26$, $P < 0.001$ at PO3, $F_{2,30} = 11.73$, $P < 0.001$ at PO5, $F_{2,30} = 4.84$, $P < 0.05$ at PO4, $F_{2,30} = 4.18$, $P > 0.05$ at PO6. The mean values of the ERPs components are shown in Table 1.

As shown in Fig. 3, the anterior P2 component in the left hemisphere had the same scale effect. The main effect of the scale of the P2 was significant. For the contralateral visual field (stimuli presented at RVF, EEG recording at the left hemisphere), $F_{2,30} = 16.74$, $P < 0.001$, and for the ipsilateral, $F_{2,30} = 13.17$, $P < 0.001$. But there was no significant difference in the right hemisphere.

Table 1. Comparison of hemisphere superiority on the P1 and P2

		Left hemisphere				Right hemisphere		
		Small	Medium	Large		Small	Medium	Large
P1	(PO3)	3.82 ±0.55	1.76 ±0.55	1.85 ±0.60 *	(PO4)	4.52 ±0.61	2.92 ±0.74	2.91 ±0.73 * *
	(PO5)	4.24 ±0.50	1.75 ±0.59	1.92 ±0.55 *	(PO6)	4.15 ±0.68	2.51 ±0.52	2.58 ±0.58
P2	(F1)	3.32 ±0.46	4.62 ±0.41	4.64 ±0.55 *	(F2)	3.81 ±0.33	4.89 ±0.32	5.11 ±0.44
	(F3)	2.43 ±0.46	2.88 ±0.44	3.74 ±0.39 *	(F4)	3.90 ±0.51	4.81 ±0.29	5.01 ±0.30

* $P<0.01$; * * $P<0.05$.

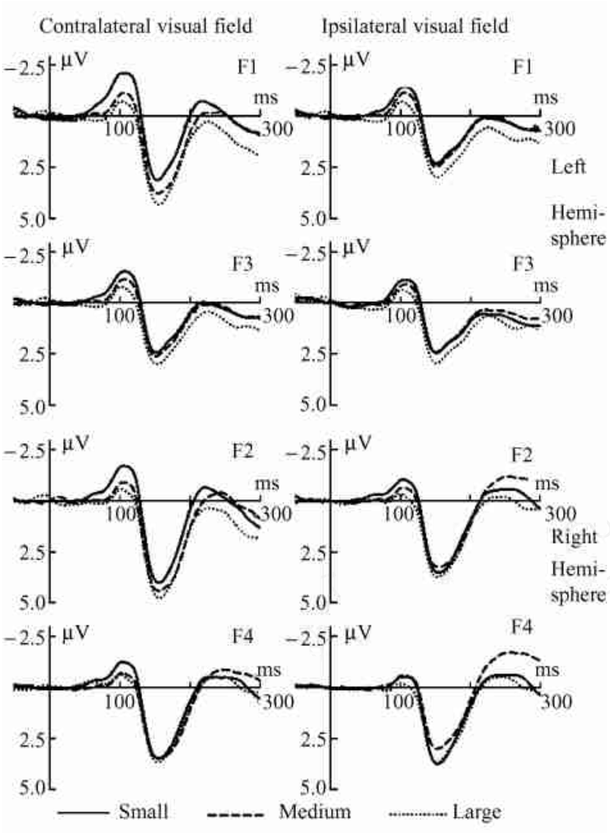

Fig. 3. ERP general average figures in the left (upper) and right hemisphere (lower).

2.4 Dipole resource

In order to estimate the location in the brain and the hemisphere predominance, the dipoles based on the three concentric shell models were analyzed with Curry software (Neurosoft Inc. V. 4.6) at each time interval ranging 60～280 ms. As shown in Fig. 4, at each point during the 80～160 ms time window, a reasonable solution could be obtained. The residual variances ranged 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: $x = -12.4$, $y = -87.3$, $z = -14.1$). Fig. 4 shows the result of an analysis on the 184～210 ms latency range. The other two dipoles, which were fixed in the symmetrical locations, 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 proved that the P1 was located at the occipital region and P2 was located at the parietal brain areas. These supported that the spatial attention was processed primarily using the "Where" pathway.

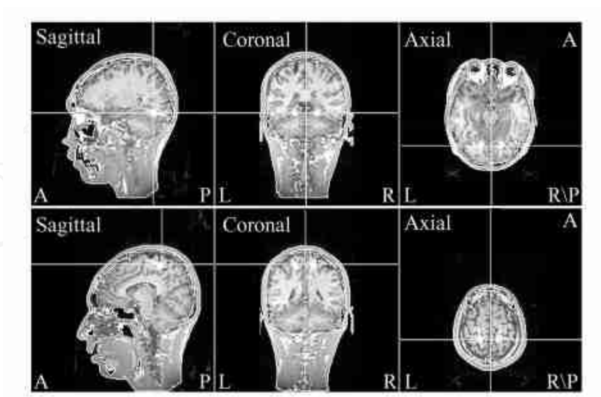

Fig. 4. The location of dipole of 80～110 (upper) and 184～210 ms (lower) after stimuli onset.

3 Discussion

The main results of the present experiment showed that with the reduction of cue scales (from large to medium to small), the RT was shortened gradually; while the P1 and N1 amplitudes evoked by small cues were significantly larger than those evoked by medium and large cues. As predicted by the spotlight theory[1,8], the energy of visual attention was limited. The smaller visual range allowed for more energy to be distributed to the single stimulus. The small cue could induce human attention to a more limited area, so the response processing was quickened and the early ERP component enhanced. Generally speaking, the amplitude of the ERP waveform reflects the intensity of the mental load during information processing, and the voltage of the amplitude was directly proportional to the amount of the activated neurons[9,14]. Higher amplitudes distributed information processing across more of the brain area. In other words, the amplitude of the ERP component increased with the energy distribution. The behavior and electrophysiological evidence in this study validated the spotlight theory, and it also suggested that the spotlight effect happened at the early period of the information processing, which consisted with the early-processed theory.

In classical research on cue-target spatial attention, the valid cue increased the P1 and N1 amplitudes[3,10,12], and the decrease of cue scale in the present study could be considered an enhancement of the cue validity. Therefore, the results in this study were in accordance with the previous results. It also affirmed that the cue scale could induce the validity of the spatial attention. The reports of the brain imaging of the P1 component showed that the scalp distribution of the P1 was mainly located at the extrastriate cortical areas, suggesting that the regulation of attention probably happened at the early period of the visual information processing. The P1 component represented the earliest period of spatial attention regulation, and the distribution of the largest P1 overlapped at extrastriate cortical areas. The ERP results of the present research showed that the posterior P1 changed obviously along with the spatial scale of the cue. The P1 effect evoked by the target stimuli suggested that the neural regulation of the spatial cue of the attention happened at the very early period (i.e. 83～160 ms) after the onset of the stimulation. This is probably located at the extrastriate cortical areas. The source of the dipole was located at the lateral occipital region, which complied with the location of extrastriate cortical areas.

In addition, the P2 amplitude at the anterior of the right hemisphere was much higher than that at the corresponding area in the left hemisphere for all visual stimuli that appearing in the LVF/RVF. This demonstrates that the right hemisphere functions more actively when subjects conduct the visual search. The hemisphere superiority occurred at the late period of information processing. In the neuropsychological research, the patients with pre-existing brain damage in the right parietal region had spatial attention defects. Patients with brain damage in the left parietal region, on the other hand, did not experience such spatial attention defects[15]. Generally consider that the right hemisphere is preponderant for the spatial attention[16]. In the study, we found that the scale effects of the P1 and P2 components in the left hemisphere were significant. The P1 amplitude decreased with the increase of cue scale, while the P2 amplitude enhanced with the increase of cue scale. There were two kinds of separation in the P2 effect. One was the separation of the P1 effect and P2 effect, which showed that the spotlight effect happened at the early period of the selected attention. The enlargement of attentive range at the late period required additional computation. The other separation was between the left and right of the P2 effect. The amplitude of P2 component in the right hemisphere generally increased, while the scale effect in the left hemisphere was stronger. This result showed that the attention processing related to variable cue range mainly occurred in the left hemisphere. Our team believes these findings challenge the traditional understanding that the right hemisphere dominates in information processing of visual spatial attention.

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