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Short Communication

Neural correlates of within-level and across-level attention to multiple compound stimuli

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ARTICLE INFO

Article history:
Accepted 11 January 2006
Available online 13 February 2006

Keywords:
Within-level
Across-level
Attention
Compound stimulus
ERPs

Abbreviations:
ANOVA, repeated measures analyses of variance
EEG, electroencephalogram
ERP, event-related potential
ISI, interstimulus intervals
LVF, left visual field
RVF, right visual field
SF, spatial frequency

ABSTRACT

Event-related potentials (ERPs) were recorded to investigate the neural mechanisms of attention to the same or different levels of two compound letters presented concurrently in the left and right visual fields, respectively. Relative to the condition when attention was allocated to the global level of one compound stimulus and the local level of another one (across-level attention), attention to the same level of the two compound stimuli (within-level attention) increased an early positivity between 100 and 140 ms (P1) over the occipito-parietal cortex. A long-latency positivity between 320 and 560 ms (P3) over the central–parietal area was also increased in the within-level relative to across-level attention conditions. The ERP results suggest that, relative to across-level attention, within-level attention to multiple compound stimuli facilitates both early sensory-perceptual processing and late process of stimulus evaluation and identification in hierarchical analysis.

Hierarchical stimuli in our visual environment consist of global structures made up of local parts. Visual attention can be focused on a specific (global or local) level of a compound stimulus or divided among more than two levels of a compound stimulus. Event-related brain potential (ERP) studies have shown that, relative to attention to the global level of Navon-type compound stimuli (Navon, 1977) as those in Fig. 1, attention to the local level increases the amplitude of an occipital positive activity between 80 and 120 ms (P1) after sensory stimulation (Han et al., 1997). Local attention relative to focused global attention also elicits an enhanced long-latency negative wave (N2) but decreases the P3 amplitudes (Han et al., 1997). Neuroimaging studies showed further that global attention induces stronger extrastriate activation in the right hemisphere whereas local attention generates enhanced extrastriate activity in the left hemisphere (Fink et al., 1996; Han et al., 2002). Similar ERP and neuroimaging results have been observed in a divided attention paradigm in which attention is divided between the global and local level of a single compound

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0006-8993/$ – see front matter
doi:10.1016/j.brainres.2006.01.028

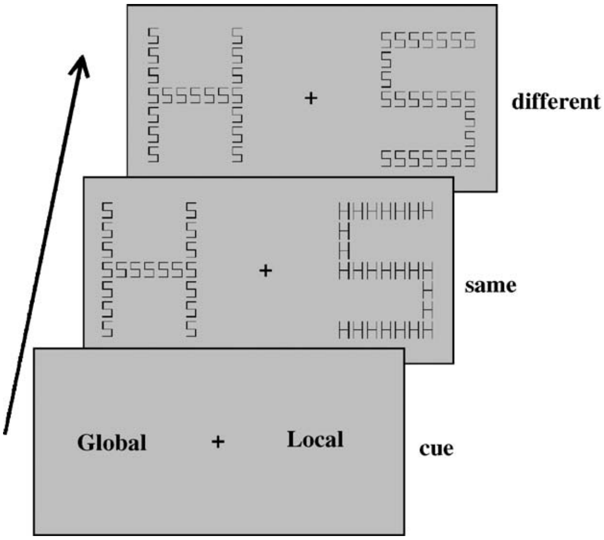

Fig. 1 – Illustration of the compound stimuli and experimental procedures of the current study. This figure shows the condition when subjects were asked to identify whether the global letter in the LVF was the same as the local letters in the RVF. Subjects should make a "yes" response to the first stimulus display but a "no" response to the second stimulus display.

stimulus in the same block of trials (Fink et al., 1996; Han et al., 2000), suggesting that similar neural mechanisms are involved in differentiating global/local processing of compound stimuli when attention is focused on one level or divided between two levels of a compound stimulus.

Most previous studies have manipulated attention to the global or local level of a single compound stimulus (Fink et al., 1996; Han et al., 1997; Heinze and Münte, 1993; Proverbio et al., 1998). However, since the perceptual system is often confronted simultaneously with multiple compound stimuli, it is important to examine how the neural system deals with the processing of these. Existing research using multiple compound stimuli has usually asked subjects to attend to one compound stimulus while ignoring the other: but it has been shown that while subjects can ignore the local properties, they cannot ignore the global properties of the unattended compound stimulus (Paquet and Merikle, 1988; Paquet, 1992). In addition, attention to the global or local level of one of the multiple compound stimuli also induces modulations of ERP components such as the P1 and N2 components (Evans et al., 2000) and results in the involvement of the temporal and parietal cortex in global and local processing, respectively (Han et al., 2004).

Since previous studies asked subjects to pay attention only to one of the multiple compound stimuli or to the same level (global or local) of the two compound stimuli, they were unable to examine the mechanisms of attention to different levels of multiple compound stimuli. The current study recorded ERPs from subjects while they were asked to attend to the same level of two compound letters (within-level attention) simultaneously presented in the left (LVF) or right (RVF) visual field, or to attend to the global level of one compound stimulus and attend to the local level of another compound stimulus (across-level attention). This was used to investigate the hypothesis that across-level attention is dissociated from within-level attention by distinct neural mechanisms.

Table 1 shows RTs and response accuracies in each condition. ANOVAs performed on RTs indicated a reliable main effect of Level of Attention ($F(1,13) = 53.39$, $P < 0.001$). Post hoc analysis confirmed that responses were faster in the global–global than local–local condition ($F(1,13) = 16.77$, $P < 0.005$). The responses were also faster in the within-level than across-level attention conditions ($F(1,13) = 108.42$, $P < 0.001$). However, RTs in the latter two conditions did not differ from each other ($F(1,13) = 1.19$, $P > 0.3$). Neither the main effect of Response Type nor its interaction with Level of Attention reached significance ($P > 0.5$).

ANOVAs of response accuracies showed a significant main effect of Level of Attention ($F(1,13) = 30.22$, $P < 0.001$). Post hoc analysis showed that response accuracy was higher in the global–global than local–local conditions ($F(1,13) = 12.06$, $P < 0.005$). The response accuracy was also higher in the within-level than across-level attention conditions ($F(1,13) = 36.95$, $P < 0.001$). Response accuracies in the latter two conditions did not differ from each other ($F(1,13) = 1.55$, $P > 0.2$). The ANOVAs also revealed a significant main effect of Response Type ($F(1,13) = 26.25$, $P < 0.001$). There was also a significant interaction between Level of Attention and Type of Response ($F(1,13) = 9.49$, $P < 0.001$). Post hoc analyses confirmed that "Yes" responses were more accurate than "No" responses only in the across-level attention condition ($F(1,13) = 28.09$, $P < 0.001$).

Fig. 2 illustrates grand-averaged ERPs in different attention conditions at an electrode over the middle occipito-parietal site, and the voltage topographies of each ERP component. Compound stimuli in all the conditions evoked a positive deflection between 90 and 140 ms (P1) over the occipito-parietal area followed by a negative component between 150 and 200 ms (N1) over the lateral occipital sites. There was also a long-latency negativity between 240 and 300 ms over the posterior area (posterior N2) and the central areas (anterior N2) which was followed by a positivity between 320 and 520 ms (P3) over the central–parietal sites.

ANOVAs with two levels of attention performed on ERP data first confirmed that the mean P1 amplitudes recorded at electrodes over the middle occipito-parietal area at 100–140 ms

Table 1 – Mean RTs (ms) and % correct under each conditions

Attention level	Same		Different	
	G–G	L–L	G–L	L–G
RTs				
"Yes" response	526	635	779	772
"No" response	547	626	752	798
% correct				
"Yes" response	88.4	84.0	50.2	53.9
"No" response	89.1	80.5	38.5	44.9

G–G = left global and right global; L–L = left local and right local; G–L = left global and right local; L–G = left local and right global.

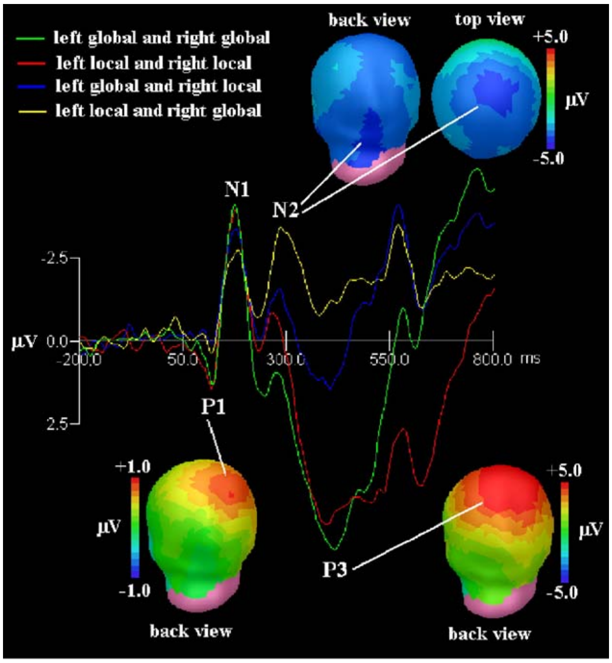

Fig. 2 – Illustration of ERPs at an electrode over the occipito-parietal area in different attention conditions. The voltage topographies show locations of the maximum amplitudes of the P1, N2, and P3 components.

were larger in the within-level than across-level attention conditions ($F(1,13) = 5.1$, $P < 0.04$). There was a similar pattern of attentional modulation of the N1 component, but the effect did not reach significance ($F < 1$). The ANOVAs with four levels of attention showed a reliable effect of Level of Attention between 240 and 300 ms at electrodes over the occipito-parietal electrodes ($F(3,39) = 7.15$, $P < 0.001$) due to the fact that the N2 amplitudes were largest when subjects attended to the local level of the left compound stimulus but the global level of the right compound stimulus and the N2 amplitudes were smallest when subjects attended to the global level of both compound stimuli. The mean P3 amplitudes at 320–480 ms were also larger in the within-level than across-level attention condition ($F(1,13) = 15.88$, $P < 0.001$). In particular, there was no evident P3 in the condition when subjects attended to the global level of the left compound stimulus and the local level of the right compound stimulus.

The behavioral data from the current experiment showed that the identification of global letters of both compound stimuli presented concurrently was faster and more accurate than the identification of local letters of the compound stimuli, replicating a global precedence effect when a single compound stimulus was of task relevance (Han et al., 1999; Navon, 1977). Moreover, we found that subjects responded faster and more accurately in the within-level than across-level attention conditions, suggesting that the visual system finds it easier to attend to the same level of multiple compound stimuli than to divide attention among different levels of multiple compound stimuli. It is noticeable that response accuracy was about 50% in the across-level attention condition. This does not necessarily mean that subjects were guessing in these conditions (i.e., that subjects did not pay attention to the left local and right global targets or the reverse as required by the instruction). A pure “guessing” condition would result in both low response accuracy and the same ERPs in the local–global and global–local attention conditions. However, the differences in ERPs between these conditions (i.e., both the N2 and P3 components) indicate that subjects were able to differentiate the two conditions.

One possible explanation for the better behavioral performance in within-level compared with across-level attention conditions is based on the hypothesis that global and local processing is mediated by low and high spatial frequency (SF) channels, respectively (Ivry and Robertson, 1999), and suggests that the visual system cannot concurrently enhance selection of high SF information in one hemifield while enhancing selection of low SF information in the other hemifield. Alternatively, since perceptual grouping of local elements and selection of an individual local element is involved in global and local perception, respectively (Han et al., 1999), the current results may suggest that the brain is unable efficiently to perform a grouping process in one hemifield concurrently with a selection process in another hemifield.

The ERP data show that the within-level and across-level attention to multiple compound stimuli modulated both short- and long-latency neural activities elicited by those stimuli. The P1 component over the middle occipito-parietal area was enlarged in the within-level attention condition relative to the across-level attention condition. This may not simply result from enhanced selection of low or high SF information because prior work has shown that selective attention to low and high SF stimuli is indexed by modulation of early evoked potentials with different polarity (Martinez et al., 2001) whereas the present ERP data showed that within-level attention to both the global (possibly enhanced selection of low SFs) or local (possibly enhanced selection of high SFs) level of multiple compound stimuli resulted in a similar pattern of P1 modulation, i.e., increasing the P1 amplitude. As the P1 component has generators in the extrastriate cortex (Heinze et al., 1994), the P1 attention effect observed here may reflect the benefit of early sensory-perceptual processing in the visual cortex when attention is focused on a narrow (either high or low) band of SF information from a visual display. The sensory-perceptual processing of a visual display may be impaired when the visual system is forced to select high SFs from one hemifield but low SFs from another hemifield, leading to decreased amplitudes of visual activity.

The present study also shows that within-level attention to multiple compound stimuli enhanced the P3 component over the central–parietal region whereas the P3 amplitude did not differ between the conditions of attention to the global or the local level of the two compound stimuli. It has been suggested that the P3 component reflects the process of stimulus evaluation and classification and the confidence with which perceptual decisions are made (Hillyard and Picton, 1987). In the current experiment, the within-level attention to multiple compound stimuli first benefited the early sensory-perceptual processing. Consequently, the later process of stimulus evaluation and recognition was also facilitated, and as a result, subjects were much more confident in making judgments in the within-level compared with across-level attention conditions. This analysis fits well with the higher response accuracy found in the within-level compared with across-level attention conditions.

Attention to the local level of LVF stimuli and to the global level of RVF stimuli induced an enhanced N2 component over both the central and posterior areas compared with other attention conditions. This is interesting because, under this condition, the local and global properties are initially projected to the right and left hemispheres, respectively. The right and left hemispheres have been shown to be efficient in processing global and local information, respectively (Fink et al., 1996; Han et al., 2002; Ivry and Robertson, 1999; Martinez et al., 1997). If the N2 wave reflects processing related to stimulus categorization and identification (Mulder, 1986; Ritter et al., 1983), the enlarged N2 observed in the condition of attention to the local level of LVF stimuli and to the global level of RVF stimuli suggests that, relative to other attention conditions, increased neural activities were induced when the right hemisphere was initially involved in local processing while the left hemisphere was initially involved in global processing. Given that the left and right hemispheres dominate local and global processing, respectively (Ivry and Robertson, 1999), the N2 results imply that global/local processing requires more neural resources in the inefficient hemisphere. The attentional modulation of the N2 was also indicated by finding the smallest N2 amplitudes in the condition of attention to the global level of both compound stimuli. It appears that within-level attention to the global aspects requires least neural resources at this stage of processing.

While previous studies using presentation of multiple compound stimuli have examined attention to one of the compound stimuli or to one (global or local) level of the compound stimuli, the present study investigated across-level attention to multiple compound stimuli. Our behavioral and ERP data demonstrate that across-level attention to multiple compound stimuli is more difficult than within-level attention. In addition, the ERP results provide electrophysiological data for understanding the neural mechanisms behind the advantage of the within-level attention, involving a mechanism of amplitude modulation of an early ERP wave at 100–140 ms and a long-latency ERP component at 320 to 480 ms. Mechanisms of both early sensory-perceptual processing and late processes of stimulus evaluation are involved in the facilitation of behavior responses in the within-level relative to the across-level attention condition.

Fourteen undergraduate and graduate students (8 men, 6 women, aged between 18 and 26 years) participated in this study as paid volunteers. All participants were right-handed, had normal or corrected-to-normal vision, and gave informed consent.

The stimuli were global letters ("S" and "H") made up of local letters ("S" and "H") in a 7 × 7 matrix, as shown in Fig. 1. The global and local letters in one compound stimulus were always different, i.e., the stimuli always contained one S and one H on the global or local level. At a viewing distance of 120 cm, global letters were 2.1° wide and 3.0° high and local letters were 0.22° wide and 0.35° high. The compound letters were dark against a grey (116 cd/m^2) background. Each stimulus display consisted of two compound letters presented concurrently in the LVF and RVF, respectively. The distance between the fixation and inner edge of each compound stimulus was 1.6°.

A fixation cross was continuously visible at the center of a 21-inch monitor. Each trial began with the presentation of two compound letters to the left and right of the fixation simultaneously for 400 ms. The interstimulus intervals (ISI) varied randomly between 1300 and 1700 ms. There were four stimulus conditions. Depending on the condition, subjects were required to discriminate whether (1) the left and right global letters were same or different (global–global condition); (2) the left and right local letters were same or different (local–local condition); (3) the left global letter was the same as or different from the right local letters (global–local condition); (4) the left local letters were the same as or different from the right global letter (local–global condition). Each block of trials began with two words ("Global" and "Local") in the LVF and RVF, respectively, which indicated the target levels (global or local) and target locations (LVF or RVF). For example, a left "Global" and a right "Local" indicated that subjects had to identify if the left global letter was the same as the right local letters (see Fig. 1). The two words remained on the screen until subjects initiated a block by pressing a button.

After 100 trials for practice, 4 blocks of 48 trials were presented for each stimulus condition. The stimuli were delivered in a random order in each block of trials. Subjects pressed one of the two buttons to make "YES" or "NO" responses. The order of stimulus conditions was counterbalanced across subjects. Half of the subjects made "YES" response with the left index finger and "NO" responses with the right index finger. A reverse assignment was given to the other subjects. Subjects were asked to fixate on the central cross during the task and to respond as quickly and accurately as possible.

The electroencephalogram (EEG) was recorded from 120 scalp electrodes, which were labeled with numbers from 1 to 120. Electrodes 59–71 were arranged along the midline of the skull. Other electrodes were located approximately symmetrically over the two sides of the skull. The skin resistance of each electrode was made less than 5 kΩ. The position of each electrode was measured with a probe for sensing the 3D position of the probe tip with respect to a magnetic field source in the head support. The recording from an electrode at the right mastoid was used as reference. Eye blinks and vertical eye movement were monitored with electrodes located below the right eyes. The horizontal electro-oculogram was recorded from electrodes placed 1.5 cm lateral to the left and right external canthi. The EEG was amplified (band pass 0.15–70 Hz) and digitized at a sampling rate of 250 Hz. The ERPs in each stimulus condition were averaged separately off-line with averaging epochs beginning 200 ms before stimulus onset and continuing for 1000 ms. Trials contaminated by eye blinks, eye movements, muscle potentials exceeding ±50 mV at any electrode, or wrong behavioral responses were excluded from the average. Voltage topographies were plotted on a representative subject's head model.

Mean voltage of ERPs was obtained (a) at 20-ms intervals starting at 60 ms after stimulus onset and continuing until 200 ms post-stimulus, and (b) at 40-ms intervals from 200 to 800 ms poststimulus. Statistical analysis was conducted on each pair of electrodes over the central, parietal, and occipito-temporal regions and those along the midline of the skull.

Reaction times (RTs) and response accuracies were subjected to repeated measures analyses of variance (ANOVAs) with Level of Attention (global–global, local–local, global–local, and local–global) and Response Type (Yes vs. No response) as independent variables. The ERP components were subjected to ANOVAs with factors being Level of Attention and Hemisphere (electrodes over the left or right hemisphere). There were four levels of attention (global–global, local–local, global–local, and local–global) or two levels of attention (within-level attention vs. across-level attention) in the ANOVAs of ERP data.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (Project 30225026 and 30328016), the Ministry of Science and Technology of China (Project 2002CCA01000). Yi Jiang's current address: Department of Psychology, University of Minnesota, 75 East River Road, Minneapolis, MN 55455, USA. We thank Robin Gilmour for helpful comments on the final version of this paper.

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