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Are Objects the Same as Groups?

ERP Correlates of Spatial Attentional Guidance by Irrelevant Feature Similarity

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Abstract

It has been proposed that the most fundamental units of attentional selection are “objects” that are grouped according to Gestalt factors such as similarity or connectedness. Previous studies using event-related potentials (ERPs) have shown that object-based attention is associated with modulations of the visual-evoked N1 component, which reflects an early cortical mechanism that is shared with spatial attention. However, these studies only examined the case of perceptually continuous objects. The present study examined the case of separate objects that are grouped according to feature similarity (color, shape), by indexing lateralized potentials at posterior sites in a sustained-attention task that involved bilateral stimulus arrays. A behavioral object effect was found only for task-relevant shape similarity. Electrophysiological results indicated that attention was guided to the task-irrelevant side of the visual field due to achromatic-color similarity in N1 (155-205 ms post-stimulus) and early N2 (210-260 ms) and due to shape similarity in early N2 and late N2 (280-400 ms) latency ranges. These results are discussed in terms of selection mechanisms and object/group representations.

Keywords

Attention, Object, Grouping, Similarity, Event-related potential, N1

Are Objects the Same as Groups? ERP Correlates of Spatial Attentional Guidance by Irrelevant Feature Similarity

1. Introduction

While numerous studies have focused on interactions between perception and attention systems (for recent reviews, e.g., Beck & Kastner, 2009; Carrasco, 2006; Hopf et al., 2005; Van der Stigchel et al., 2009), object-based attention has been characterized as a function of the bottom-up control of attentional deployment, which is based on perceptual processing that constructs object representations (e.g., Desimone & Duncan, 1995). A consistent notion is that objects are the most fundamental units of attentional selection (for reviews, Driver & Baylis, 1998; Scholl, 2001), which has been proposed based on convergent evidence that representations of task-irrelevant spatial locations/features are facilitated if they belong to the same object or group as a task-relevant location/feature, in behavioral experimental psychology studies (e.g., Driver & Baylis, 1989; Duncan, 1984; Egly et al., 1994; Kramer & Jacobson, 1991), neuroimaging studies (e.g., Martinez et al., 2006; Muller & Kleinschmidt, 2003; O'Craven et al., 1999; Schoenfeld et al., 2003), and neuropsychology studies in brain-damaged patients (e.g., Driver, 1995; Humphreys, 1999). Object-based attentional selection appears consistent with our rapid and effortless cognition and action toward objects in daily life.

A critical issue in this area is the nature of the objects that attention selects, or what is an “object” (Scholl, 2000). Since various visual structures tend to be intuitively defined as objects, it has been claimed, to avoid subjectivity, that behavioral “object-based attention effects” in response time (RT) or accuracy should be criteria for being “objects” (Watson & Kramer, 1999). According to this definition, as well as explicit objects such as rectangles or connected elements, separate elements that are grouped by Gestalt factors such as adjacency or feature similarity may be considered “objects” (Baylis & Driver, 1992; Driver & Baylis,

1989; Duncan & Humphreys, 1989; Gilchrist et al., 1996). In this context, rectangles involve boundary closure (Marino & Scholl, 2005), and connected elements involve connectedness as grouping factors (Palmer, 2003; Watson & Kramer, 1999). Thus, objects are groups, or “grouped arrays of locations” (Vecera, 1994), with respect to visual representations on which attention operates, and the amount of object-based attention effects can be an objective index for the extent of perceptual grouping (Driver & Baylis, 1998). However, it is unclear whether the same selection processes are involved in object-based attention for an explicitly-connected object and for a group of separate objects, since selective attention involves multiple stages of processing (Luck & Hillyard, 1999).

The purpose of the present study was to examine object/group-based spatial selection according to feature similarity, by the use of event-related potentials (ERPs) that provide fine temporal resolution of brain activities. ERPs have been well investigated with regard to the psychological mechanisms of selective attention, and their neural bases, and should be useful for revealing the mechanisms of object-based attention. ERP research has identified multiple selection processes in spatial attention. ERP components at posterior electrode sites including the visual-evoked P1 (with a peak at 90-140 ms poststimulus) and N1 (at 140-190 ms) are modulated in amplitude by spatial attention, which is proposed to reflect a sensory gain-control mechanism (e.g., Hillyard et al., 1999). The N2pc component (N2 posterior-contralateral) is typically elicited at around 200-350 ms after stimulus-onset contralateral to the side of the target or to the just-attended side of the visual field at that moment in visual-search tasks (e.g., Kiss et al., 2008; Woodman & Luck, 1999). The present study used a sustained focal attention task that involved bilateral stimulus arrays (Heinze et al., 1990, 1994; Woldorff et al., 2002), where the task was to respond when an infrequent target was presented at an attended hemifield during a rapidly presented sequence of bilateral stimuli. Electrophysiological spatial attention was indexed by larger amplitudes of posterior

ERPs over the hemisphere contralateral, rather than ipsilateral, to the attended hemifield. In this paradigm, attention-related amplitude modulations were found at P1 and N2 (220-280 ms) for non-targets or standards (Woldorff et al., 2002). According to the scalp distributions and source modeling, the amplitude modulation for N2 was considered to reflect an attention-related re-entrant activation of the P1 attention effect.

Using a sustained focal attention task that involved bilateral stimulus arrays (Heinze et al., 1990, 1994; Woldorff et al., 2002), we previously examined object/group-based spatial attention for connected objects (Kasai, 2010; Kasai & Kondo, 2007). By controlling the symmetrical structure of bilateral stimuli, Kasai (2010) found that the typical P1 attention effect (150-210 ms post-stimulus onset) was obtained, regardless of the connectedness of the bilateral stimuli, but, importantly, the subsequent N1 attention effect (150-200 ms) and N2 (310/330-390 ms) showed decreases in amplitudes in the connected conditions. Note that previous studies with the bilateral-stimulus paradigm have not reported the N1 attention itself, perhaps due to a confounding of grouping factors. The results of Kasai (2010) suggested that, since connectedness was irrelevant to the task, spatial attention was obligatorily spread or guided to the opposite side of the object region to the task-relevant side. Furthermore, the specific stimulus manipulations (unconnected, weakly-connected, and strongly-connected conditions) led to the following interpretation: N1 is associated with the extent of perceptual grouping because the attention effect diminished as connectedness increased, and N2 is associated with the unity of an object because the attention effect diminished for connected objects regardless of the degree of connectedness.

Using the same experimental paradigm as in the previous study for connected objects (Kasai, 2010), the present study tested the case of grouping according to similarity in achromatic color or contrast polarity (one lighter and one darker than a grey background), or in simple geometric shapes (see Figure 1). Three stimulus conditions were tested: similar

condition, dissimilar-color condition, and dissimilar-shape condition. Although these were not strictly colored stimuli (e.g., red or green in isoluminant conditions), here we conventionally use the term “color” in the context of similarity according to the literature (e.g., Palmer, 2003). While bilateral stimuli were rapidly presented in random order, the participants were required to press a button if the infrequent target (i.e., circle or square) appeared at an attended hemifield among a sequence of standard stimuli (oval or rectangle). Stimuli with different widths (thin and thick) were selected for the left and right sides to make an asymmetric figure, since symmetry is also a grouping factor (e.g., Saiki, 2000) and may cause a ceiling effect (Kasai, 2010; Kasai & Kondo, 2007). All combinations of widths, colors, and shapes were presented in equal probability so that estimates of attention and grouping effects are collapsed across physical differences, i.e., different similarity conditions involved the same stimuli at particular locations, but the similarity relations between bilateral stimuli differed.

Many ERP studies have noted an enhancement of N1 in response to stimuli that belong to an unattended region of an attended object, both for spatial cueing and sustained-attention tasks using physical or illusory rectangles (He et al., 2004; Kasai, 2010; Martínez et al., 2006, 2007a, 2007b), or human-head geometry or connectedness (Verliger et al., 2008). This convergent evidence for an object-based N1 attention effect may indicate a single and general selection process for object-based attention, which is partly shared with spatial attention. However, previous ERP studies have only examined the case of explicit objects that were defined by connectedness, closure, or inducers for illusory perception. Thus, it is unknown whether the grouping of separate elements causes the same effect.

In the present study, if attentional selection based on similarity-based grouping involves the same mechanism as that of connected objects, the spatial attention effect on N1 should decrease in the similar condition compared to that in the dissimilar conditions. On the other

hand, there is little evidence for an object-based spatial attention effect for N2 (e.g., Kasai, 2010), and the nature of this effect remains largely unspecified. If the N2 object-based effect is associated with the unity of an object as in the previous interpretation, it should not be seen for the grouping of separate elements.

----- Figure 1 about here -----

2. Results

2.1. Behavioral Data

Table 1 summarizes the behavioral results. There were no statistically significant results regarding Hits and FAs. Hits and FAs were considered in the signal detection analyses. In the results, mean d' ranged from 2.6 to 2.8 and criterion ranged from 0.73 to 0.83 across the similarity conditions. There was only a significant main effect of attended location, which indicates that d' was higher for the attend-right condition than for the attend-left condition [2.6 vs. 2.8, $F(1, 12)=5.4, p=0.039$].

For RTs, there was a main effect of grouping [$F(2, 24)=4.7, \epsilon=0.70, p=0.034$]. Planned comparisons of this effect showed that RTs were slower for the similar condition than for the dissimilar-shape condition [mean object-based effect = 14 ms, $t(12)=3.0, p=0.01$ (two-tailed)], while those for the similar condition did not significantly differ from those for the dissimilar-color condition [mean object-based effect = 4.4 ms, $p=0.195$].

----- Table 1 and Figure 2 about here -----

2.2. ERP Data

In grand-averaged ERPs in response to standard stimuli, several attention effects were revealed by comparing differences between ERPs recorded at electrode sites ipsilateral and contralateral to task-relevant visual fields, which were most prominent at the occipital temporal brain area (Figures 2, 3, and 4).

----- Figure 3 and 4 about here -----

As shown in Figure 2a, P1 (100-140 ms) had a greater amplitude at contralateral than at ipsilateral sites for all grouping conditions equally, which was reflected by the main effect of laterality [$F(1,12)=8.2, p=0.014$]. The amplitude of N1 (155-205 ms) was also greater at contralateral than at ipsilateral sites, as reflected by the significant effect of laterality [$F(1,12)=5.8, p=0.033$]. However, the attention effect was different for the different stimulus configurations (Figure 2b), which was reflected by the interaction of grouping and laterality [$F(2,24)=6.0, \epsilon=0.92, p=0.01$]. First, to identify the color- and shape-similarity effects on the N1 attention effect, planned comparisons were conducted for the contralateral minus ipsilateral subtraction ERPs (Figure 2c left), and the N1 attention effect for the similar condition was significantly smaller than that for the dissimilar-color condition [$t(12)=3.2, p=0.008$ (two-tailed)], while there was no comparable difference between the similar and dissimilar-shape conditions [$p=0.189$]. Second, we tested whether the attentional modulations were specified at contralateral or ipsilateral electrode sites (Figure 3) by post-hoc tests separately for contralateral and ipsilateral sites, but the similarity effects were not statistically significant [$p=0.59$ at contralateral sites, $p=0.095$ at ipsilateral sites].

The early N2 latency range (210-260 ms) had a main effect of grouping [$F(2,24)=6.1, \epsilon=0.91, p=0.009$], due to a more positive amplitude for the dissimilar-color condition (Figure 2). However, there were also attentional modulation effects by similarity (Figures 2a and 2b), as reflected by an interaction of grouping and laterality [$F(2,24)=8.3, \epsilon=0.87, p=0.003$]. Planned comparisons for contra minus ipsi ERPs (Figure 2c middle) indicated that the N2 attention effect for the similar condition was significantly smaller than those for the dissimilar-color condition [$t(12)=3.5, p=0.004$] and the dissimilar-shape condition [$t(12)=2.6, p=0.023$]. This interaction was mainly due to a difference at ipsilateral sites (see Figure 3), which was reflected by a significant grouping effect only at ipsilateral sites [$F(2,24)=10.2, \epsilon=0.99, p=0.001$]. Further post-hoc comparisons (Bonferroni correction)

showed that the amplitude in the early N2 latency range at ipsilateral sites was more positive for the dissimilar-color condition than for the similar condition ($p=0.004$).

The following attention effects were observed as small and broad deflections (late N2, 280-400 ms), which were the greatest for the dissimilar-shape condition (Figure 2b). In this latency range, there was a main effect of hemisphere [$F(1,12)=6.0, p=0.031$] and a grouping x laterality interaction [$F(2,18)=4.4, \epsilon=0.94, p=0.024$]. Planned comparisons for subtraction ERPs (Figure 2c right) showed that the late N2 attention effect for the dissimilar-shape condition was shifted to a more negative direction than that for the similar condition [$t(12)=3.0, p=0.011$], while there was no comparable difference between the similar and dissimilar-color conditions [$p=0.321$]. Post-hoc tests for the interaction did not find similarity effects at contralateral ($p=0.17$) or ipsilateral sites ($p=0.78$).

----- Figure 5 about here -----

Figure 4 shows that spatial attention effects (ERPs in the left-attend condition minus those in the right-attend condition) at each latency range had similar posterior scalp distributions across the similarity conditions, although those in the early and late N2 latency ranges were not very clear. Figure 5 shows the effect of similarity on spatial attention (i.e., double subtraction). Note that the amplitude of the color-similarity effect on the N1 attention effect was greatest at occipital-temporal sites, similar to that for the N1 attention effect itself. The early N2 modulation for color similarity and the late N2 modulation for shape similarity were also maximum at occipital-temporal sites.

3. Discussion

The goal of this study was to identify electrophysiological manifestations of object-based spatial selection for objects/groups that were defined by color or shape similarity. The object-based ERP attention effects were indicated by a decrease of lateralized spatial attention effects, i.e., a difference of hemispheric activations in relation to covert spatial

attention. In the results, P1 (100-140 ms) was increased over the hemisphere contralateral to the attended side with respect to the ipsilateral side, equally across similarity conditions. Spatial attention effects were also found for the N1 (155-215 ms post-stimulus), early N2 (210-260 ms), and late N2 (280-400 ms). Importantly, however, the N1 and early N2 spatial attention effects were decreased in association with color similarity, and the early and late N2 attention effects were decreased in association with shape similarity. To our knowledge, these are the first ERP correlates of attention-spreading associated with perceptual grouping for separate visual elements.

3.1 A common mechanism in object-based attention

We observed modulation of the N1 spatial attention effect by color similarity, consistent with the results of previous studies with explicitly continuous objects (e.g., He et al., 2004; Kasai, 2010; Martínez et al., 2006, 2007a, b). This suggests that there is a common early sensory mechanism of object-based spatial selection for continuous and discrete objects/groups. Note that the stimuli used in the present study required quite long-range interactions in the visual cortex to induce object-based effects, because two separate stimuli lay in the left and right visual fields, respectively. Although this arrangement is a common in object-based attention research (e.g., Ben-Shahar et al., 2007; Baylis & Driver, 1992; Egly et al., 1994; Watson & Kramer, 1999), visual grouping is often examined by using matrix stimuli that involve many elements and tasks that explicitly require the participant to group whole elements in human electrophysiological studies (e.g., Casco et al., 2009; Han et al., 2005; Nikolaev et al., 2008) and in single unit studies of monkey (e.g., Yokoi & Komatsu, 2009). Since it has been reported that attentional operations for a few large elements and those for many small elements were not the same with regard to developmental trajectory (e.g., Kimuchi et al., 2005), these stimuli may involve separate mechanisms. The present results of N1 modulations demonstrate that even widely separate elements can be grouped

according to color similarity in an obligatory fashion, via the same early cortical mechanism as connected objects.

However, shape similarity did not cause N1 modulation, but rather caused early and late N2 modulations. Since the processing timing of grouping may differ according to Gestalt factors that define grouping (e.g., Casco et al., 2009; Han et al., 2005), this result suggests that shape similarity requires more processing time than color similarity. This notion may be supported by a computational view, in which shape is a boundary feature that is extracted from contrast information in surface features, such as color or luminance (Cavanagh et al., 1990). Another possibility, however, is that the extent of shape similarity is smaller than that of color similarity in the present study: the shapes of bilateral stimuli were not exactly the same in the similar condition, due to symmetry control. Further studies are required to systematically examine the extent and type of feature similarity.

Previous studies that have combined ERPs and neuroimaging techniques revealed that the neural origin of the object-based spatial modulation effect of N1 was the lateral occipital cortex (Martinez et al., 2006, 2007a, b), which also plays a role in Kanisza-figure perception (e.g., Murray et al., 2004). N1 modulation has also been found for object-based selection with overlapped surfaces generated by moving dots (Khoe et al., 2005; Pinilla et al., 2001; Valdes-Sosa et al., 1998) and for attention in three-dimensional space (Kasai et al., 2003). Thus, N1 may reflect the perception of a highlighted-object segregated from the background and the extent of connectedness (Kasai, 2010). The present study extends these notions to the grouping of separate elements, although it depends on the type or strength in grouping operations.

3.2 Subsequent object-based spatial attention effects

In the present study, we found that subsequent N2 spatial attention effects were also modulated by stimulus configurations, as in the previous study of connectedness (Kasai,

2010), which is consistent with a behavioral finding which suggested that there are multiple stages of processing for object-based selection (Awh et al., 2001) and with a neurocomputational model that visual grouping involves rapid feedforward and late feedback processing (Roelfsema, 2006). However, the early N2 attention effect (210-260 ms) was modulated specifically at the hemisphere ipsilateral to the attended side. In addition, the modulation of late N2 by shape similarity was a broad effect (280-400 ms), inconsistent with the previous N2 effect (310/330-390 ms) associated with object unity (Kasai, 2010).

In sustained-selective attention tasks, selection negativity (SN) is typically elicited at around the N2 latency in response to stimuli with an attended feature (e.g., color, motion), rather than unattended feature, and is dependent on spatial attention (e.g., Anllo-Vento & Hillyard, 1996). The latency of SN varies according to the discriminability of attended/unattended features (e.g., Kasai & Morotomi, 2001; Smid et al., 1997), and its scalp distribution varies according to selected feature dimensions (Anllo-Vento & Hillyard, 1996). Thus, SN may reflect a matching process between the attentional trace of features and stimuli, the neural origins of which are located in cortical areas that are specialized for the processing of particular features (for a review, Hillyard & Anllo-Vento, 1998). If the present N2 attention effects were due to SNs, they would indicate that the activations associated with a task-relevant feature (i.e., shape) can be spread over bilateral stimuli. However, this consideration is inconsistent with the notion that the N2 attention effect for bilateral stimulus arrays reflects a re-entrant activation of the P1 attention effect (Woldorff et al., 2002).

On the other hand, the modulation of early N2 at ipsilateral sites might represent an overlap of Pd (distractor positivity), which is a subcomponent of N2pc (Hickey et al., 2009). Pd is elicited at the hemisphere contralateral to a distractor and reflects an aspect of inhibition in a visual-search display. If the present early N2 effect were due to Pd, it may reflect an inhibition of the segregated item in the irrelevant visual field. This account is

consistent with the fact that the positivity in this latency range was the largest for the dissimilar-color condition, because a color singleton is more salient than a shape singleton (Theeuwes, 1995). However, the present focal-sustained attention task qualitatively differs from visual search tasks. Future studies should explore ERP correlates associated with inhibitory mechanisms in sustained spatial-attention tasks.

3.3 Relationship of behavioral and electrophysiological results

Although the experimental paradigm in the present study was specialized for ERPs, we found a behavioral object/group-based attention effect for shape similarity. This effect occurred under conditions in which physical stimulus differences were collapsed and could serve as a test of object-based selection (Watson & Kramer, 1999). The RT object-based effect (14 ms) is comparable to those observed in previous behavioral studies (e.g., Baylis & Driver, 1992; Driver & Baylis, 1989; Kramer & Jacobson, 1991; Richard et al., 2008) and suggests that attentional resources to discriminate the target were decreased at the task-relevant location because of attention-spreading to the opposite side of the perceptual group by shape similarity.

In contrast, we did not find a behavioral object-based effect due to color similarity. This does not necessarily indicate that object/group selection did not occur. The selection of objects/groups may occur via a transient attention-spreading over object representations, so that behavioral object-based effects may appear only under conditions or timings at which perceptual attention-spreading affects response execution. One critical condition for determining the presence of behavioral object-based attention effects may be task relevancy. Color was task-irrelevant in the present study; i.e., the task was to discriminate shapes (circles and squares vs. ovals or rectangles). Lamy & Tsal (2000) showed that object features are activated only when they are relevant to the task and suggested that attention selects from a representation that codes grouped arrays of locations with their features.

The present ERP and behavioral results suggest that there may be a task-independent process and a task- and feature-dependent process in object-based attention, as reflected by the N1 color-similarity effect and late N2 shape-similarity effect, respectively. These considerations may be clarified by further experiments that are designed to analyze ERPs in response to target stimuli.

3.4 Conclusions

The present study showed that an early sensory ERP component (N1) can be modulated according to the feature similarity of separate visual elements, as previously observed for connected objects (Kasai, 2010), and that this modulation can vary according to the feature type, strength of similarity, or task relevance. From a theoretical perspective, these results support the notion that “groups” have in some respects the same status as “objects” as units of selective attention (e.g., Driver & Baylis, 1998) and cast light on whether connectedness is the most primitive grouping factor or has a special role (Palmer, 2003; Watson & Kramer, 1999). The present study also showed that several selection mechanisms were involved, which may indicate that the visual system has several different mechanisms for forming grouped arrays and that behavioral object-based effects may reflect different aspects of them. Although more systematic examinations are required, electrophysiological measures can be useful for exploring interactions between object processing and attention.

4. Experimental Procedure

4.1. Participants

Fourteen volunteers (6 females), aged 19 to 33 years (mean 23.2 years), participated in this study. Data from one volunteer were excluded from the analyses due to excessive muscle potentials. Participants reported normal or corrected-to-normal vision, and provided their written informed consent. The experiment was conducted following the guidelines laid down in the Helsinki Declaration and were approved by the local ethics committee.

4.2. Stimuli and Procedure

The stimuli consisted of black and white shapes against a gray background (Figure 1) that were displayed on a Hitachi monitor and controlled by PsyScope on a personal computer (Macintosh G3) with a PsyScope button box (Cohen et al., 1993). The viewing distance was 80 cm and a central fixation cross that extended across a visual angle of 1.0 x 1.0 degrees was presented throughout the experiment. Bilateral stimuli were displayed horizontally 3.56 degrees to the left and right and 1.28 degrees above the fixation point (to the inner edges). Each stimulus was an oval or rectangle that was 1.07 degrees in height and of different widths. Standards extended horizontally 0.71 or 1.43 degrees, and targets extended 1.07 degrees (i.e., circle or square).

Bilateral stimuli consisted of either two standard stimuli at 75 % probabilities or one standard and one target in the separate hemi-fields at 25 % probabilities. For bilateral standards, stimuli of different widths (thin, thick) were selected for the left and right sides to make an asymmetric display. For each bilateral-standard trial and target-containing trial, all combinations of widths, colors (black or white), and shapes (oval or rectangle) were randomly presented in equal probability to the left and right hemi-fields, except for combinations of dissimilar color and dissimilar shape (see Figure 1). Bilateral stimuli had the same achromatic color and shape in the similar condition, and these differed only with respect to color in the dissimilar-color condition, or with respect to shape in the dissimilar-shape condition.

The bilateral stimuli were presented for 100 ms, and the inter-stimulus interval (offset to onset) was randomly varied between 300 and 500 ms (5 steps, rectangular distribution). With the short ISI, the ERPs in response to successive stimuli overlapped. However, the overlap should not differ among conditions due to the random order of stimulus presentation (Hillyard & Münte, 1984).

The participant was seated in a reclining chair in a sound- and electric- shielded room and instructed to attend to either the left or right hemi-field during the blocks and to press a button with the right thumb in response to the target (i.e., square or circle) presented in the attended field as accurately and quickly as possible. It was emphasized that they had to maintain fixation and to try not to move their eyes during the block. The attend-left and attend-right conditions consisted of 12 blocks, respectively, each consisting of 100 trials, which were alternated. The initial visual field to be attended was counterbalanced across the participants. The experiment started with 1-3 practice blocks for each attention condition to stabilize task performance and eye movement.

4.3. Recordings and Analyses

The electroencephalogram (EEG) was measured using an electrocap (Electro-Cap International) with 25 Ag-AgCl electrodes (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz, O2, PO7, PO3, POz, PO4, and PO8 according to the International 10-20 System), which were referenced to the nose. Blinks and horizontal eye movements were monitored with electrodes at the outer canthi of the eyes (horizontal electrooculogram [EOG]) and Fp2 and below the right eye (vertical EOG). The impedance of the electrodes was kept below 10 kOhm. EEGs were filtered with a bandpass of 0.1-30 Hz and sampled at 200 Hz.

Behavioral performance was measured, including the percentage of correct target detections (hits) and RTs for hits. Responses were scored as correct if they occurred within 300-1000 ms after a target was presented in the attended location. Responses to other stimuli were classified as false alarms (FAs). The behavioral measures were subjected to repeated-measures analysis of variance (ANOVA): the factors considered were grouping (similar, dissimilar color, dissimilar shape) and attention condition (attend left, attend right), and stimulus type (standard, unattended target) for FAs.

Further ERP analyses were conducted only for standard stimuli to examine ERP components associated with visuo-spatial selection, while those associated with terminal decision and motor processes were separated (Hillyard & Münte, 1984). ERPs were averaged separately for each similarity condition and for each attention condition, while collapsing the types of width, color, and shape. Averaging epochs were 1000 ms, starting 200 ms before the onset of the stimulus and ending 800 ms post-stimulus, while correcting for differences in the 200-ms pre-stimulus baseline. Automatic artifact rejection was applied to eliminate epochs contaminated above $75 \mu\text{V}$. Epochs with incorrect responses and those immediately after responses (regardless of accuracy) were excluded. The average of retained epochs was 79 %.

ERPs at the occipital-temporal sites (PO7, PO8) were quantified by mean amplitudes with latency windows of 100-140 ms (post-stimulus) for P1, 155-205 ms for N1, 210-260 ms for P2/early N2, and 280-400 ms for late N2. The measurements were subjected to repeated-measures ANOVA: the factors considered were grouping (similar, dissimilar color, dissimilar shape), laterality of the electrode sites relative to the attended visual field (ipsilateral, contralateral), and hemisphere (left, right). The Greenhouse-Geisser correction was used to reduce the positive bias resulting from repeated factors with more than two levels. If the interaction between grouping and laterality was statistically significant, to clarify the attention effects, subtraction ERPs (contralateral vs. ipsilateral) were applied to planned comparisons between the similar and dissimilar conditions (*t*-test, two-tailed), and used to identify grouping effects with similar color or shape on attentional deployment, respectively.

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Figure Captions

Figure 1. Stimuli used in the present experiment. All combinations of bilateral standards are presented. The participants were required to respond if a target (below) was presented at the attended hemi-field.

Figure 2. Grand-average ERPs at the occipito-temporal electrodes (PO7, PO8). a) ERPs at hemisphere sites contralateral and ipsilateral to an attended visual field are overlapped, so that the left and right sites are collapsed. b) Difference waves for the attention effect, i.e., ERPs at ipsilateral sites were subtracted from those at contralateral sites. c) Mean amplitudes of the contralateral minus ipsilateral attention effect. Intervals of confidence were calculated following Loftus and Masson (1994).

Figure 3. Grand-average ERPs at the occipito-temporal electrodes (PO7, PO8) are overlapped according to the grouping conditions at hemisphere sites contralateral and ipsilateral to an attended visual field, respectively.

Figure 4. Scalp distributions of spatial attention effects for each similarity condition: ERPs in the attend-right conditions were subtracted from those in the attend-left conditions.

Figure 5. Scalp distributions of effects of similarity on spatial attention. Double subtractions were made to confirm whether the similarity effects were modulations of N1, early N2, or late N2 attention effects. The spatial attention effects (left-attend minus right-attend) of ERPs in the dissimilar conditions (color, shape) were subtracted from those in the similar condition.

Table 1
Summary of Behavioral Data

| | | Similar | | Dissimilar color | | Dissimilar shape | |
|----------------------|-------------------|----------|-----------|------------------|-----------|------------------|-----------|
| | | <i>M</i> | <i>SE</i> | <i>M</i> | <i>SE</i> | <i>M</i> | <i>SE</i> |
| Reaction time (ms) | Attend left | 516 | 11 | 509 | 7 | 499 | 10 |
| | Attend right | 506 | 8 | 504 | 10 | 495 | 10 |
| Hit rate (%) | Attend left | 67.3 | 3.3 | 67.6 | 3.1 | 69.8 | 2.5 |
| | Attend right | 72.9 | 2.4 | 70.7 | 2.7 | 72.5 | 2.2 |
| False-alarm rate (%) | Attend left | | | | | | |
| | Standard | 2.9 | 1.0 | 3.0 | 0.9 | 3.7 | 1.4 |
| | Unattended target | 2.3 | 0.8 | 2.3 | 0.9 | 2.1 | 0.6 |
| | Attend right | | | | | | |
| | Standard | 3.0 | 1.3 | 2.0 | 0.8 | 2.6 | 0.9 |
| | Unattended target | 2.6 | 1.1 | 2.6 | 1.2 | 2.8 | 1.2 |

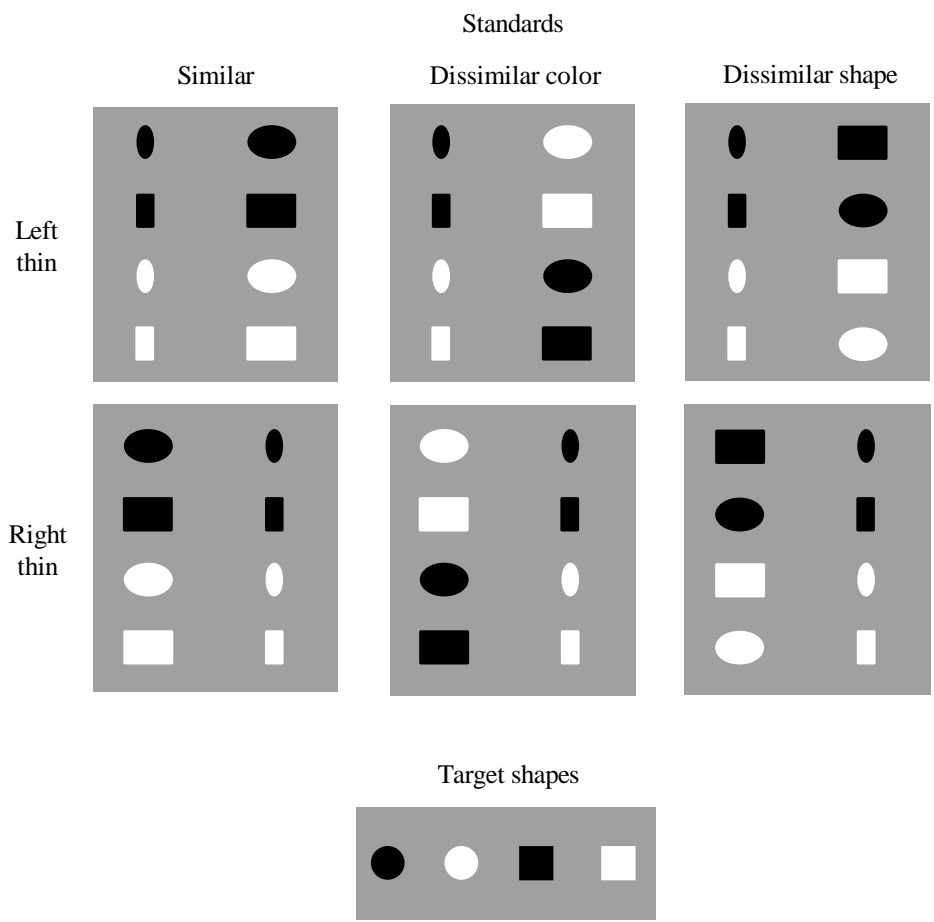


Figure 1

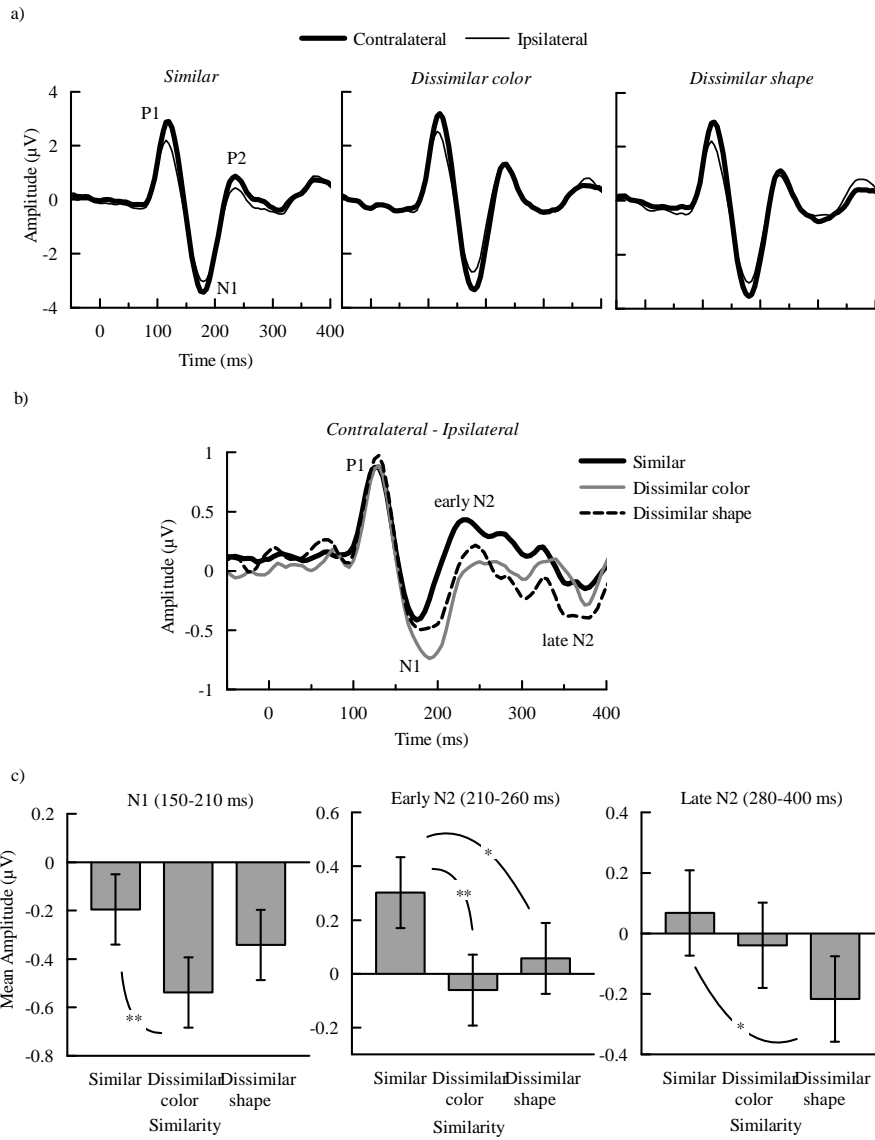


Figure 2

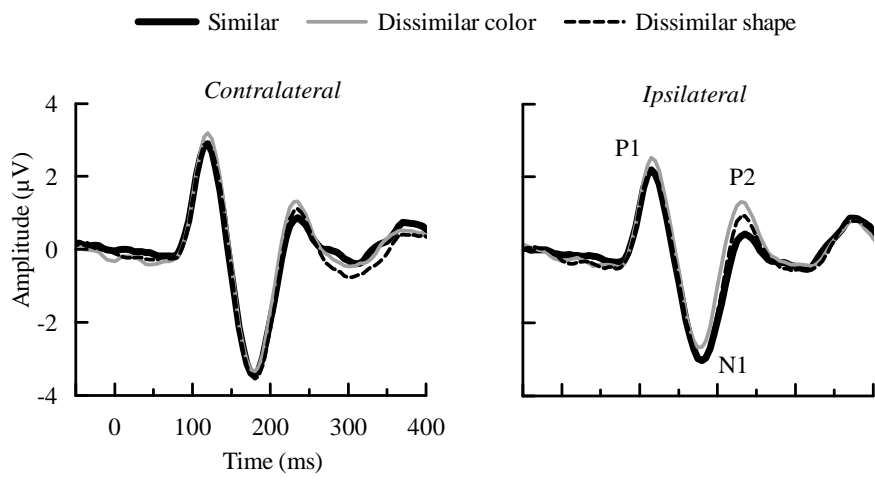


Figure 3

Attention Effects (Left-attend minus Right-attend)

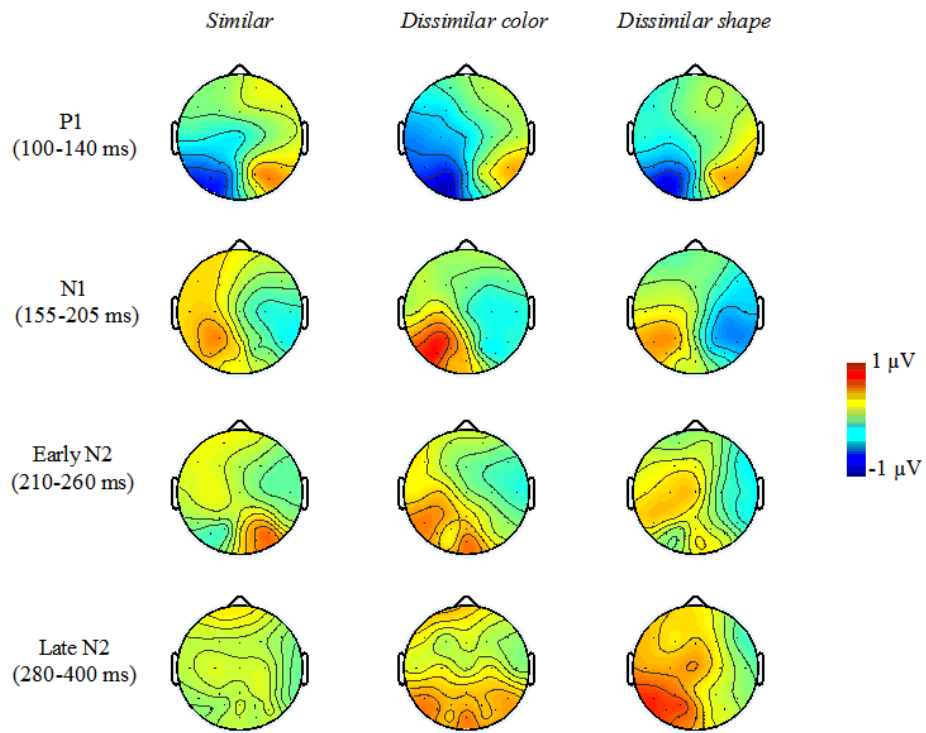


Figure 4

Double Subtractions
(Attention effects for similar minus attention effects for dissimilar)

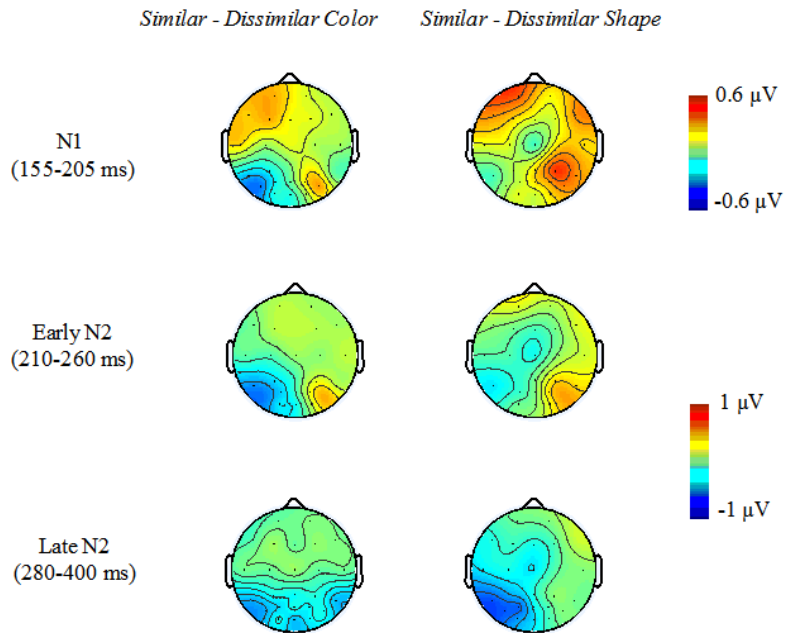


Figure 5