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Research Report

Differentiating spatial and object-based effects on attention: An event-related brain potential study with peripheral cueing

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ABSTRACT

en spatial an~~d object-based attention under condi~~tions in which spatial ere enhanced by increasing the cue validity and the task load. The data ious results, with the effects of spatial attention found in an enhanced he effects of object-based attention emerged in an enhanced posterior N1. on effect maps and current source density maps confirmed the distinct These results support the proposal that, under peripheral cueing, spatial ct attention are associated with activity respectively in anterior and uctures, and further suggest a distinction between how attention ng under conditions of central cueing and peripheral cueing.

1. Introduction

Attention can select spatial locations (space-based attention) or perceptual objects (object-based attention) that may be formed preattentively. Space-based attention facilitates responses to the stimuli within the selected area of the visual field (Posner, 1980), whereas object-based attention facilitates selection of whole objects (Scholl, 2001). Effects of object-based attention have been confirmed in numerous studies using both divided and directed attention. In a divided attention task, participants have to select multiple attributes for their responses. Performance is typically better when the attributes belong to a single object than when they belong to (and attention is divided across) different perceptual objects (Blaser et al., 2000; Duncan, 1984; Watson and Kramer, 1999). In a directed attention task, attention is cued to a location in

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space. Detection of a subsequent target is typically better when the target falls within the object where attention is cued, compared with when the target appears the same distance away but in a different object (Egly et al., 1994; Müller and Kleinschmidt, 2003; Valdés-Sosa et al., 1998).

A key question is whether object-based attention and spatial attention modulate visual processing in similar ways. Though both effects can influence behavioral responses (reaction times [RTs] and errors) (see Scholl, 2001), it is possible that the effects are differentiated at a neural level. Neuroimaging data on this are mixed. Some studies suggest that object-based attention and space-based attention share the same neural network (Arrington et al., 2000; Müller and Kleinschmidt, 2003), however other studies have found that activation in striate and extrastriate cortices was modulated by object attention, while more anterior regions (including prefrontal cortex) were activated by spatial attention (Fink et al., 1997). Moreover, because of the low temporal resolution of functional magnetic resonance imaging (fMRI), it is unclear whether patterns of common modulation operated over the same temporal intervals in the shared regions.

Studies using event-related brain potentials (ERPs) have demonstrated that spatial attention modulates electrophysiological responses at an early sensory stage, with attended stimuli having larger amplitudes for the P1 and/or N1 components (Hillyard and Münte, 1984; Hopfinger and Mangun, 1998; Luck and Hillyard, 2000; Mangun and Hillyard, 1991). Effects of object-based attention on these components have also been found in studies with superimposed perceptual objects (Khoe et al., 2005; Rodríguez and Valdés-Sosa, 2006; Valdés-Sosa et al., 1998). In a recent direct comparison of space and object-based attention effects, Martínez and colleagues used central cues to direct attention either to solid rectangles (Martínez et al., 2006) or illusory figures formed by perceptual completion (Martínez et al., 2007a,b). They found that spatial and object attention both modulated the N1 component over posterior brain regions, suggesting again that the two effects had common neural generators.

These data, however, contrast with other reports. He and colleagues (He et al., 2004) used peripheral rather than central cues to direct attention. Like Martínez et al., modulatory effects were found on the N1 component, but in this case spatial attention influenced the anterior N1 over central scalp areas, whereas object-based attention enhanced the posterior N1 over posterior (occipito-temporal) scalp areas. This anterior–posterior dissociation is consistent with spatial and object-based attention having distinct effects on sensory processing. The results also agree with data from neuroimaging studies using faces and houses as stimuli, which have shown that object attention explicitly modulates activities in stimulus-specific sensory regions (Kanwisher and Wojciulik, 2000; O'Craven et al., 1999).

The contrast between the ERP results of He et al. (2004) and those of Martínez et al. (2007a,b) suggests that different effects may occur under conditions of central and peripheral cueing. Indeed He et al. (2004) used cues with relatively low validity (58%), so that any effect may reflect exogenous orienting of attention (cf. Müller and Rabbitt, 1989), whereas central cueing is typically with high validity and engages endogenous attentional processes. Though endogenous (voluntary) and exogenous (reflexive) attention have both been associated with a common large-scale neural network (Kim et al., 1999; Peelen et al., 2004; Rosen et al., 1999), differences in brain activity have been found between the two attention systems (Arrington et al., 2000; Corbetta et al., 2000; Hopfinger and West, 2006; Kim et al., 1999; Mayer et al., 2004). Corbetta and Shulman (2002) summarized the neural architecture of these two systems, suggesting that a ventral network acts to direct attention exogenously to salient events, while a more dorsal network modulates voluntary (endogenous) attentional orienting (see also Kincade et al., 2005; Thiel et al., 2004). In their recent ERP study, Hopfinger and West (2006) suggested that there were both separate and interacting systems of spatial and object-based attention.

An alternative possibility, however, is that differences in prior ERP results may reflect the contrasting perceptual loads of the tasks. Martínez et al. used conditions of high perceptual load in which targets had to be discriminated within a stream of distractor stimuli. In contrast He et al. (2004) used conditions with a low perceptual load (simple onset detection) and conditions that promoted distributed attention across multiple locations. It is possible that attention effects are maximized under conditions of high load (cf. Lavie, 1995) and with focused rather than distributed attention (Eimer, 1994; Handy and Mangun, 2000), enabling a posterior N1 effect to emerge for spatial attention.

In the present paper we assessed whether effects of spatial attention emerge on posterior visual areas under conditions of high cue validity and perceptual load. In Experiment 1 we repeated the procedure of He et al. (2004), but used high cue validity (cues were 77% valid). In Experiment 2, we examined performance using a difficult discrimination task (e.g. Hillyard and Münte, 1984), with target stimuli having to be discriminated within a stream of distractors. We assessed whether these changes resulted in matching spatial and object-based effects attention over posterior scalp regions.

Peripheral cueing can trigger both exogenous and endogenous attentional effects, depending not only on the cue validity but also on the cue-target onset asynchrony (CTOA). Exogenous attentional effects can reach a maximum within 200 ms and then decrease, resulting in initial facilitation and later inhibition of performance after about 300 ms in detection tasks (Klein, 2000) and 500 ms in discrimination tasks (Lupiáñez et al., 2001). In contrast, endogenous attention operates more slowly (Müller and Rabbitt, 1989). Jittering the CTOA in a single experiment, then, is likely to tap different temporal stages for these two mechanisms and this may mask contrast between the conditions. Here we used a constant 300-ms CTOA, which is suitable for producing both exogenous and endogenous attentional effects (Egly et al., 1994; He et al., 2004). Effects of spatial attention are revealed by differences in responses to stimuli at the cued location (*valid* trials) and those at the uncued location in the same object (on *intra-object* trials, *intra* for short).[1] Effects of object attention are shown by

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[1] The contrast between valid and intra trials takes place between stimuli appearing in the same object and so avoids the confounding effect of making comparisons across different objects, which could be influenced by object-based attention. Note also that, even if attention is attended to objects it may still spread across space (Vecera and Farah, 1994), so an effect of spatial attention may still be expected. This would also be predicted based on the original behavioral study of Egly et al. (1994).

differences in responses to stimuli at the uncued location within the cued object (on *intra* trials) and those to stimuli equi-distant from the cue but in a different object (on *inter-object* trials, *inter* for short).

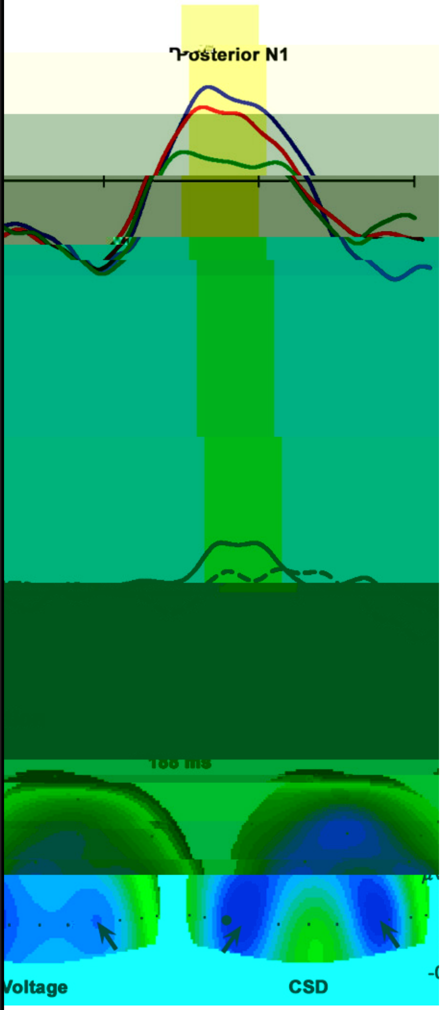
2. Results

Subjects performed an onset detection task (Experiment 1) or a form discrimination task (Experiment 2) while viewing two horizontal or vertical rectangles. Attention was directed by peripheral cueing which indicated the most probable location for the targets. The stimulus could appear at the cued location (*valid* trials), at another location in the cued rectangle (on *intra* trials), or at a location equi-distant from the cue in the other rectangle (*inter* trials) (Fig. 1). The spatial attention effect was characterized by difference between the *valid* and *intra* trials; the object attention effect was revealed by the difference between the *intra* and *inter* trials.

Behavioral results are reported in Table 1. Experiment 1 showed both space- and object-based attention effects. Object layout did not affect overall RTs [$F(1,15) = .06$, $P >$

[redacted]

ean amplitudes of the anterior N1, distrib-
ntro-parietal region. In contrast, an object-
ffect was significant in the mean amplitudes
1, ranging over the temporo-occipital areas
This differential distribution can clearly be



Spatial attention effect is evident in
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Table 2 – Mean ERP amplitudes and ANOVA results of the cue-target relation factor

	Component	Mean amplitudes ± SE			Main effect		Pairwise comparisons	
		Valid	Intra	Inter	Attention		Spatial attention (valid vs. intra)	Object attention (intra vs. inter)
		μV			F(2,30)	P	P	
Experiment 1	P1	1.08 ± 0.61	1.18 ± 0.57	1.24 ± 0.56	.23	n.s.		
	Anterior N1	−4.09 ± 0.65	−2.54 ± 0.64	−2.33 ± 0.64	27.88	<.0001	<.0001	n.s.
	Posterior N1	−1.79 ± 0.55	−1.25 ± 0.57	−0.51 ± 0.61	6.46	<.013	n.s.	<.005
Experiment 2	P1	1.38 ± 0.41	1.51 ± 0.52	1.66 ± 0.42	.52	n.s.		
	Anterior N1	−1.90 ± 0.66	−0.15 ± 0.64	0.40 ± 0.82	20.41	<.0001	<.0005	n.s.
	Posterior N1	−1.39 ± 0.34	−1.01 ± 0.36	−0.25 ± 0.53	8.09	<.003	n.s.	<.009

witnessed in the voltage and current topograph maps of the spatial and object-based attention effects. The normalization procedure (McCarthy and Wood, 1985) also confirmed the distribution difference between the two attention effects [$F(5,75)=7.18$, $P<.0004$].

In Experiment 2, a long-lasting spatial effect was evident after the N1 time range. This effect was very strong and could be even identified at posterior electrode sites. However, voltage and current density maps at a later time period (200 ms) show that this late spatial effect was again anteriorly distributed, mainly over the central scalp area. Therefore, it was confirmed that the posterior N1 was only modulated by object-based attention.

3. Discussion

He et al. (2004) found that spatial and object-based attention showed different scalp distributions on their effects on the N1 component of the ERP response. Enhancement of the anterior N1 was linked to space-based attention while enhancement of the posterior N1 was linked to object-based attention. The present results replicated these results in two experiments. Experiment 1 used the same simple detection task as He et al. (2004), but with a higher cue validity in order to engage endogenous as well as exogenous components of attention. The manipulation was successful in that a significant effect of spatial attention was apparent on behavior. Experiment 2 used a difficult form discrimination task at the cued locations rather than the simple detection task employed previously (He et al., 2004, also Experiment 1 here). Despite this change, the pattern of results essentially replicated the findings from Experiment 1. We still observed a dissociation in the scalp distributions of the space- and object-based effects on the N1 component. The spatial attention effect was distributed over the centro-parietal region (affecting the anterior N1), while the object-based attention effect was found across occipito-temporal areas (modulating the posterior N1). The scalp potential and CSD maps also confirmed these scalp distribution differences.

With a higher cue validity than that used by He et al. (2004) Experiment 1 showed a significant spatial effect in behavior. This suggests that spatial attention was more intensively engaged than it was in He et al., supporting our notion that the spatial effect here comes from voluntary attention (He et al., 2004). Despite this difference across the studies, however, there were few differences in the early effects apparent in the ERP data. The similar spatial modulations in the anterior N1 across the studies suggest that the present manipulation of cue validity did not greatly affect early stages of visual attention. This suggests that, with peripheral cueing, increasing the validity of the cue may affect later processes (e.g., setting a bias to respond to the cued location) but not early vision. In Experiment 2, the engagement of spatial attention was enhanced by reducing the relevant locations and by increasing the task load. The cue in this case was a 100% spatially valid cue because target discrimination was required only at the cued location. While the discrepancy between effects in the anterior and posterior N1s remained intact, the spatial effect was strong and lasted a longer time, and it was then noticeable even in more posterior areas. Although our conclusions should be tentative because different subjects were tested across experiments, our observations agree with a study by Handy and Mangun (2000), in which an enhanced spatial attention effect (in the posterior N1, however) was found when task load and cue validity increased.

Previous studies have provided converging evidence that the posterior N1 effect originates from extrastriate cortex, more precisely the middle occipital gyrus and the ventral fusiform gyrus. In contrast, the anterior N1 effect has sources in the parietal lobe near the intraparietal sulcus (Di Russo et al., 2001, 2003; Martínez et al., 2001). Our observation from the CSD maps is consistent with these results, with the spatial attention effect on the anterior N1 having a current density maximum over the centro-parietal region and the object selection effect on the posterior N1 having distributed current density peaks in occipito-temporal cortex. Hence it may be suggested that the space-based anterior N1 effect observed here originated from the parietal lobe and the object-based posterior N1 effect arose from extrastriate cortex. The data suggest that space- and object-based attention result in distinct modulations of early neural activities.

Our results coincide with a recent electrophysiological study on monkeys. In that experiment, Buschman and Miller (2007) measured neuronal firing rates associated with visual search (voluntary engaging of attention) and visual pop-out (reflexive attention capture by a salient stimulus) in lateral intraparietal cortex (LIP), lateral prefrontal cortex (LPFC), and the frontal eye fields (FEF). In the voluntary attention condition, neurons in frontal areas showed attention selectivity prior to neurons in parietal cortex. In contrast, in the reflexive attention condition, attentional selectivity was observed first

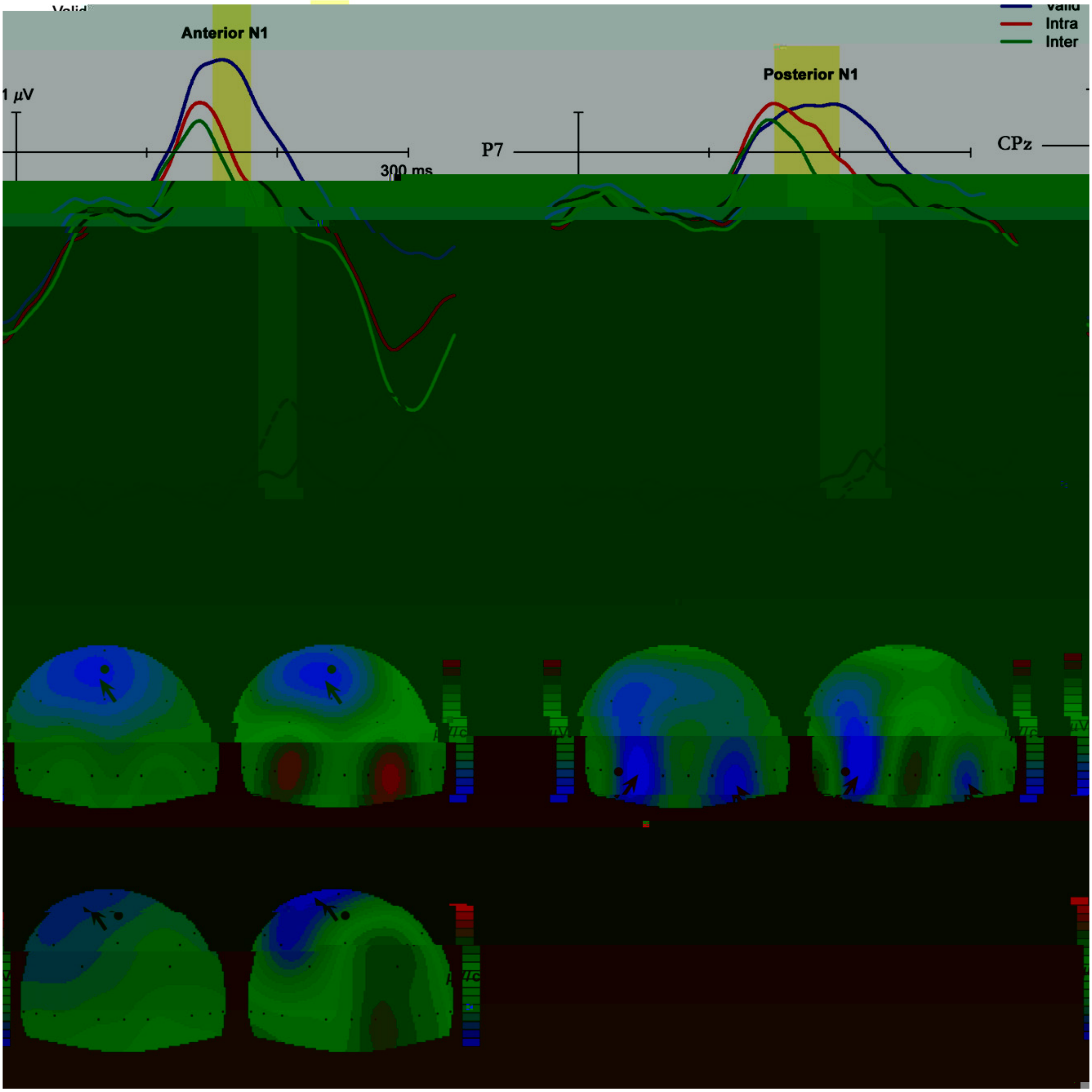

Fig. 3 – ERP results of Experiment 2. Spatial attention effect is evident in amplitudes of the anterior N1 maximal over centro-parietal sites (CPz in the illustration). Object attention effect is found in amplitudes of the posterior N1 spreading over temporo-occipital areas (P7 in the illustration). Mean amplitudes were measured within specific windows (yellow rectangles) relative to a 200-ms pre-cue baseline which is not included in the figure. The differential distribution of these two attention effects is also observed in the voltage topographs and CSD maps, which are plotted in back view.

in parietal cortex. These results emphasize the importance of anterior brain structures for voluntary attention, and more posterior structures for reflexive attention. Although the timing of brain activity in single cell recording and ERP results may differ as a function of the contrasting experimental designs, the anterior–posterior pattern observed by Buschman and Miller (2007) agrees with our previous and present data.

The present results, along with those of He et al. (2004), differ from those from Martínez and colleagues (Martínez et al., 2006, 2007a,b). In Martínez et al.'s work, the modulatory effects from space-based attention were apparent on the posterior N1, and could be located having source origins in the lateral occipital cortex. However, there was no evidence for this here. The lack of a spatial attention effect on the posterior N1 agrees with other studies of visual attention using peripheral cueing with short CTOA values (Hopfinger and Mangun, 1998, 2001; Hopfinger and Maxwell, 2005; cf. Fu et al., 2005), while it contrasts with results from studies using central cueing and/or sustained attention to a location (

pre-cue baseline (i.e., −500 to −300 ms pre-stimulus), and were applied with band-pass filtering (0.1–40 Hz) and artifact rejection (±60 μV criterion). In Experiment 1, EEG activities from all trials were analyzed. In Experiment 2, only standard trials (trials without manual responses) were analyzed.

Because the CTOA was short, the neural responses to the cue overlapped with the responses to the stimulus. However, the adjacent response filter (Woldorff, 1993) could not be employed to remove the differential overlap because the CTOA was kept constant. To rule out the possibility that any differences in early target ERP components might be due to overlapping and distortion from cue ERPs, the ERP waveforms, for each subject, were produced by taking the same number of trials from each location, each layout, and each cue-target relation into the averaging procedure. When this method was applied, the ERP activities generated by the cues and the targets still overlapped each other. However, as a whole the physical stimuli fell at the corners of the rectangles. No matter what cueing condition it was, the stimuli producing the electrophysiological responses were identical. Hence, before the targets/standards were presented, the identical cues would produce almost the same ERP waveforms. Afterwards, when the targets/standards were shown, because of the exactly matched stimuli, the differences between the critical conditions cannot be accounted for by overlapping ERPs but rather by the different attentional status of the stimuli (for detailed analysis, see He et al., 2004, Appendix).

P1, anterior N1, and posterior N1 were quantified as mean amplitudes averaged across electrodes that showed the maximal amplitudes of corresponding components. Because the ERPs were averaged over different stimulus onset locations, data from contra- and ipsi-lateral sites were combined altogether. In this case, the P1 was statistically assessed within mean amplitudes over sites P7, P8, O1, and O2, within time windows around its peak latency (80–100 ms in Experiment 1, 70–90 ms in Experiment 2), relative to the 200-ms pre-cue baseline. Similarly, the anterior N1 was measured as mean amplitudes over C3, C4, and Cz (130–160 ms in Experiment 1, 150–180 ms in Experiment 2), and the posterior N1 over P7, P8, O1 and O2 (150–200 ms in both experiments).

Behavioral and neurophysiological data were put into ANOVAs with Greenhouse–Geisser correction (Jennings and Wood, 1976). If the main effect of attention was significant, the space- and object-based attention effects were further examined with pairwise comparisons, in which the spatial attention effect was revealed by differences between valid and intra conditions, and the object attention effect was identified as differences between intra and inter conditions. Behavioral responses with RTs between 150 ms and 850 ms were recognized as correct hits. RT medians of correct hits in Experiment 1 were analyzed with a two-way ANOVA (3 attention × 2 object layout). Mean ERP amplitudes were analyzed with one-way ANOVAs, in which the object layout factor was dropped because there was a limited amount of data.

Scalp distribution of spatial and object attention effects in the N1 complex was statistically compared with the normalization method suggested by McCarthy and Wood (1985). Sixteen main electrode sites (FC3/4, C3/4/z, CP3/4/z, P3/4/z, P7/8, O1/2/z) were chosen and grouped into six scalp regions. Mean amplitudes across electrode sites within each region were measured at time points when the spatial/object attention effects reached their maxima (Experiment 1: 164 ms/176 ms, Experiment 2: 172 ms/184 ms), and then put into a two-way ANOVA (2 attention effect × 6 scalp region). Significant interaction between factors will indicate differential topographical distributions. Additionally, the distribution of these attention effects were further demonstrated by computing current source density (CSD) maps with MATLAB programs (Kayser and Tenke, 2006). CSD is a reference-independent measure of the radial current flow into the scalp surface, proportional to the surface Laplacian (i.e., the second spatial derivative) of scalp potentials (Pernier et al., 1988). It can greatly reduce the contribution of remote electrical sources to local recordings, and thus lessens the blurring effect across scalp electrical signals due to the volume conductor problem. Compared to scalp potential topographs, CSD mapping makes the appearance of the activation region more focused.

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