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Time course of spatial and feature selective attention for partly-occluded objects

Tetsuko Kasai [a,*], Ryuji Takeya [b]

[a] Faculty of Education, Hokkaido University, Sapporo, Japan
[b] Graduate School of Education, Hokkaido University, Sapporo, Japan

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ABSTRACT

Attention selects objects/groups as the most fundamental units, and this may be achieved by an attention-spreading mechanism. Previous event-related potential (ERP) studies have found that attention-spreading is reflected by a decrease in the N1 spatial attention effect. The present study tested whether the electrophysiological attention effect is associated with the perception of object unity or amodal completion through the use of partly-occluded objects. ERPs were recorded in 14 participants who were required to pay attention to their left or right visual field and to press a button for a target shape in the attended field. Bilateral stimuli were presented rapidly, and were separated, connected, or connected behind an occluder. Behavioral performance in the connected and occluded conditions was worse than that in the separated condition, indicating that attention spread over perceptual object representations after amodal completion. Consistently, the late N1 spatial attention effect (180–220 ms post-stimulus) and the early phase (230–280 ms) of feature selection effects (target N2) at contralateral sites decreased, equally for the occluded and connected conditions, while the attention effect in the early N1 latency (140–180 ms) shifted most positively for the occluded condition. These results suggest that perceptual organization processes for object recognition transiently modulate spatial and feature selection processes in the visual cortex.

1. Introduction

The visual scene is constructed from countless fragmented visual images, while coherent percepts and actions for objects are usually possible. This may be due to perceptual organization and attentional selection, the combination of which is referred to as object-based attention (for reviews, Driver & Baylis, 1998; Hopf, Schoenfeld, & Heinze, 2005; Scholl, 2001). Object-based attention may be achieved by an attention-spreading mechanism, in which the representations of task-irrelevant locations or features are obligatorily facilitated if they belong to the same object/group as task-relevant locations/features. For example, in most studies, behavioral performance in discriminating two features is better when they belong to the same object rather than to different objects (Duncan, 1984), and the shift in attention from a cued location to an uncued location is faster within an object than between two different objects in a spatial-cueing task with a two-rectangle display (Egly, Driver, & Rafal, 1994). Hemi-spatial neglect in brain-damaged patients can also be modulated by perceptual grouping with feature similarity, connectedness, or amodal completion for partly-occluded objects (Humphreys, 1999).

Event-related potentials (ERPs) with high temporal resolution are a particularly useful tool for exploring the mechanisms of mid-level perceptual operations, such as object-based attention. Previous studies have consistently found that the N1 spatial attention effect (at 140–190 ms post-stimulus) is object-based: the amplitude of N1 in response to stimuli that belong to an unattended region was enhanced when it belonged to an attended object (He, Fan, Zhou, & Chen, 2004; Martínez et al., 2006; Verleger, Groen, Heide, Sobieralska, & Jaskowske, 2008). This indicates that object-based attention shares, at least in part, a common mechanism with early spatial selection, i.e., a sensory gain-control mechanism (e.g., Hillyard, Vogel, & Luck, 1999). Furthermore, the object-based modulation of the N1 spatial attention effect is considered to originate at the lateral occipital cortex (Martínez et al., 2006; Martínez, Ramanathan, Foxe, Javitt, & Hillyard, 2007a; Martínez, Teder-Salejarui, & Hillyard, 2007b).

By using a focal attention task for bilateral stimuli, we have shown that the N1 lateralization effect according to spatial attention is modulated by the extent of perceptual grouping for connected objects (Kasai, 2010), as with grouped elements with feature similarity (Kasai, Moriya, & Hirano, 2011). Note that it is difficult to distinguish attention-spreading due to perceptual

* Corresponding author. Tel./fax: +81 11 706 3108.
E-mail address: tetsu@edu.hokudai.ac.jp (T. Kasai).

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grouping with task-irrelevant feature similarity from feature-based attention: attentional deployment occurs for stimuli with task-relevant or attended features over the whole visual field (Andersen, Fuchs, & Muller, 2011; Saenz, Buracas, & Boynton, 2002; Treue & Martínez-Trujillo, 1999). However, it is also possible that the global effect of feature-based attention is associated with perceptual grouping with feature similarity.

An interesting notion in object-based attention research is that attention-spreading may be the basis for the perceptual experience of object unity or perceptual grouping (Driver & Baylis, 1998). Therefore, the present study aimed to examine the links between the object-based N1 spatial attention effect and the visual experience of objects. According to Hulme and Zeki (2006), there are two types of object perception: awareness of the presence of an object and the direct perception of objects, which can both be examined by using occluded objects. Thus, we can perceive the presence of an object (i.e., awareness) even if it is partly occluded and invisible, which is called amodal completion. On the other hand, we can also perceive that the occluded object is fragmented by the other object and the occluded part is invisible (direct perception). Thus, we may have two perceptual experiences simultaneously. The present study focused on these two aspects of object perception, rather than consciousness itself, which is generally assessed in paradigms in which physical stimuli are held constant but the experience of the observer varies, such as with binocular rivalry (e.g., Blake, 2004). Previously, Martínez et al. (2007a, b) found that object-based modulation of the N1 attention effect occurred for illusory objects formed by inducers, suggesting that it is associated with perceptual object representations. However, this was the case for modal completion with subjective, but visible, contours, and thus it is unclear whether the results were associated with awareness or the direct perception of objects.

In the present study, we examined ERP spatial attention effects for partly-occluded objects or objects with amodal completion by using the same experimental paradigm as in our previous studies (Kasai, 2010; Kasai et al., 2011), which is basically a sustained-focal-attention task that involves bilateral stimulus arrays (Heinze, Luck, Mangun, & Hillyard, 1990; Heinze et al., 1994; Woldorff et al., 2002). The task was to respond when an infrequent target was presented at an attended hemifield during a rapidly presented sequence of bilateral stimuli. Spatial attention was indexed by larger amplitudes of posterior ERPs over the hemisphere contralateral, rather than ipsilateral, to the attended hemifield. Here, object/group-based effects decrease the ERP attention effects, reflecting attention-spreading or guidance to the opposite side of the object/group (Fig. 1a). This paradigm has some merits for examining object-based attention. First, analyses of the differences between ERPs at contralateral and ipsilateral electrode sites enable us to assess attentional operations, by dissociating them from ERPs evoked by physical stimulus properties themselves. Second, rapid presentation can lead to large numbers of ERPs, and thus systematic manipulations of object/grouping factors are possible. In addition, analyses of ERPs in response to infrequent targets may enable us to test object-based feature selection processes (Kasai & Kondo, 2007).

The present study set three stimulus conditions: separated condition, occluded condition, and connected condition (Fig. 1b). In the separated condition, bilateral stimuli (rectangles) were presented separately from the central large occluder; in the connected condition, a line physically connected the bilateral stimuli, and in the occluded condition, the connecting line was perceived as being behind the occluder. Here, the occluded objects had more similarity or grouping factors than the separated objects, since the bilateral squares had interior short lines that were similar and aligned with respect to each other (although their lengths differed according to symmetry control). Thus, any differences between the occluded and separated conditions may involve similarity or grouping, rather than amodal completion. However, the connected objects had the same geometric properties as the occluded objects and also had unified connectedness, which should cause more object-based modulation for the N1 attention effect than ununified connectedness (Kasai, 2010). Therefore, it is critical to compare the occluded condition to the connected condition to reveal processes that are associated with amodal completion or the awareness of presence of objects. If the N1 spatial attention effect of ERPs is associated with selection based on unitary-object perception that overcomes physical discontinuities, those in the occluded and connected conditions should equally be smaller than those in the separated condition.

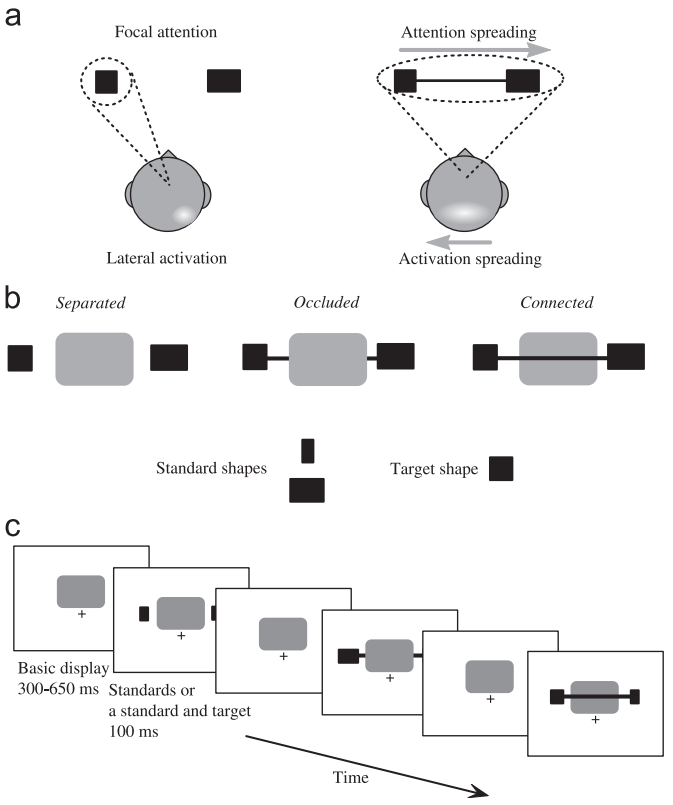

Fig. 1. (a) Schematic illustration of the attention-spreading paradigm of ERPs. Posterior lateralized activation according to spatial attention should decrease if bilateral stimuli are perceptually grouped and attention spreads. (b), (c) Stimuli and the stimulus sequence used in the present study. A central occluder remained visible and brief bilateral squares were presented with or without lines, which were behind or in front of the occluder.

2. Methods

2.1. Participants

Fourteen volunteers (8 females), aged 21 to 36 years (mean=24.2 years), participated in this study. Participants reported normal or corrected-to-normal vision, and provided their written informed consent.

2.2. Stimuli and procedure

Stimuli were displayed on a Hitachi CRT monitor, at a viewing distance of 70 cm, and controlled by PsyScope on a personal computer (Macintosh G3) with a PsyScope button box (Cohen, MacWhinney, Flatt, & Provost, 1993). A large green rectangle with curved corners (occluder) was extended at a visual angle of $3.9^\circ \times 3.0^\circ$, and was presented 0.8° (to the bottom edge) above a blue central fixation cross against a gray background throughout the experiment (Fig. 1b).