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Research Report

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.

1. Introduction

While numerous studies have focused on interactions between perception and attention systems (for recent reviews, e.g., Beck and 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 and Duncan, 1995). A consistent notion is that objects are the most fundamental units of attentional selection (for reviews, see Driver and 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 and Baylis, 1989; Duncan, 1984; Egly et al., 1994; Kramer and Jacobson, 1991), neuroimaging studies (e.g., Martínez et al., 2006; Müller and 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, 2011). 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

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and 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 and Driver, 1992; Driver and Baylis, 1989; Duncan and Humphreys, 1989; Gilchrist et al., 1996). In this context, rectangles involve boundary closure (Marino and Scholl, 2005), and connected elements involve connectedness as grouping factors (Palmer, 2003; Watson and 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 and 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 and 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 post-stimulus) 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 and 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 and 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 gray background), or in simple geometric shapes (see Fig. 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 and Kondo, 2007). All combinations of widths, colors, and shapes were presented in equal probability so that estimates of attention and grouping

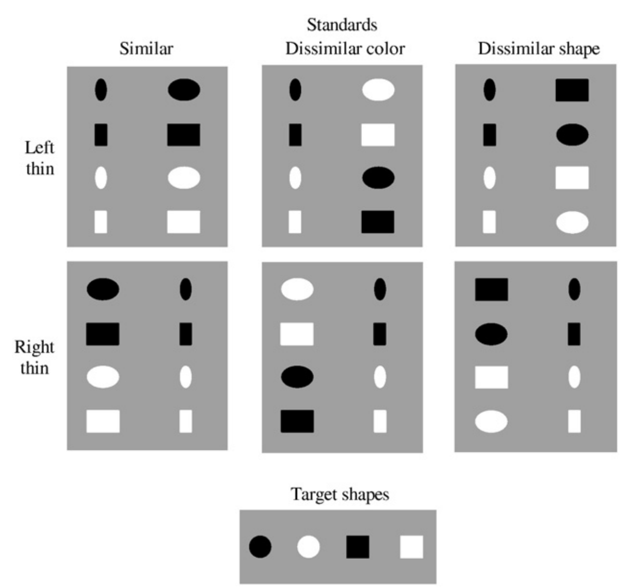

Fig. 1 – Stimuli used in the present experiment. All combinations of bilateral standards are presented. The participants were required to respond if a target (below) was presented at the attended hemifield.