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Perceptual organization, visual attention, and objecthood

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ABSTRACT

We have previously demonstrated that the mere organization of some elements in the visual field into an object attracts attention automatically. Here, we explored three different aspects of this automatic attentional capture: (a) Does the attentional capture by an object involve a spatial component? (b) Which Gestalt organization factors suffice for an object to capture attention? (c) Does the strength of organization affect the object's ability to capture attention? Participants viewed multi-elements displays and either identified the color of one element or responded to a Vernier target. On some trials, a subset of the elements grouped by Gestalt factors into an object that was irrelevant to the task and not predictive of the target. An object effect – faster performance for targets within the object than for targets outside the object – was found even when the target appeared after the object offset, and was sensitive to target–object distance, suggesting that the capture of attention by an object is accompanied by a deployment of attention to the object location. Object effects of similar magnitude were found for objects grouped by a combination of factors (collinearity, closure, and symmetry, or closure and symmetry) or by a single factor when it was collinearity, but not symmetry, suggesting that collinearity, or closure combined with symmetry, suffices for automatic capture of attention by an object, but symmetry does not. Finally, the strength of grouping in modal completion, manipulated by varying contrast polarity between and within elements, affected the effectiveness of the attentional capture by the induced object.

1. Introduction

Perceptual organization and visual attention are crucial for the perception of our visual environment and to visuomotor behavior. Perceptual organization refers to the processes by which the disjoint bits of visual information are structured into the larger coherent units that we eventually experience as environmental objects. The Gestalt psychologists, who were the first to study perceptual organization, suggested that organization is composed of grouping and segregation processes (Koffka, 1935; Köhler, 1938; Wertheimer, 1938), and identified several stimulus factors that determine organization. These include grouping factors such as proximity, good continuation, similarity, common fate, and closure (Wertheimer, 1938), and factors that govern figure-ground organization, such as surroundedness, relative size, contrast, convexity, and symmetry (Rubin, 1958). Modern researchers have identified additional factors: Common region (Palmer, 1992) and element connectedness (Palmer & Rock, 1994), which support grouping, and familiarity (Peterson & Gibson, 1994), lower region (Vecera, Vogel, & Woodman, 2002), spatial frequency (Klymenko & Weisstein, 1986), top–bottom polarity (Hulleman & Humphreys, 2004a), and extremal edges (Palmer & Ghose, 2008), which support figure-ground assignment. Psychophysical research have provided quantitative measures for many of the classical and new factors and documented their role in perceptual organization and object perception (e.g., Elder & Zucker, 1993, 1994; Feldman, 2001; Kellman & Shipley, 1991; Kimchi, 2000; Kubovy & Wagemans, 1995; for recent reviews see, Peterson & Kimchi, 2013; Wagemans et al., 2012).

Visual attention refers to the processes by which some visual information in a scene is selected, in particular, information that is most relevant to ongoing behavior. Deployment of attention can be goal-directed, based on deliberate behavioral goals of the observer (e.g., Desimone & Duncan, 1995; Egeth & Yantis, 1997; Posner, 1980). Deployment of attention can also be stimulus-driven. In this case, attention is captured involuntarily by certain stimulus events, such as a salient singleton (e.g., Theeuwes, De Vries, & Godjin, 2003), or an abrupt onset of a new perceptual object and some other types of simple luminance and motion transients (e.g., Abrams & Christ, 2003; Franconeri, Simons, & Junge, 2004; Jonides, 1981; Yantis & Hillstrom, 1994).

The relationship between perceptual organization and visual attention is multifaceted and mutually constrained

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(e.g., Driver, Davis, Russell, Turatto, & Freeman, 2001; Scholl, 2001; van Leeuwen et al., 2011; for recent reviews see, Gillebert & Humphreys, 2015; Kimchi, 2009). Findings such as greater disruptive effect of response-incompatible distractors on target discrimination when the target and distractors are strongly grouped by Gestalt factors (e.g., Kramer & Jacobson, 1991), easier responding to two features when they belong to the same object than when they belong to two separate objects (e.g., Duncan, 1984), and the smaller cost associated with target detection when attention is initially cued to a non-target location for targets that appear in the same object as the cue than for targets appearing in a different object (e.g., Egly, Driver, & Rafal, 1994), demonstrate that perceptual organization constrains attentional selection. Further evidence comes from studies with patients with attention deficits, showing for example, a recovery from extinction as a result of grouping contralesional items with ipsilesional items on the basis of Gestalt factors (e.g., Mattingley, David, & Driver, 1997), and from fMRI and ERPs studies that found that attended and unattended stimuli belonging to the same object elicited a very similar response pattern in the visual cortex (e.g., Martinez, Teder-Salejarvi, & Hillyard, 2007; Martinez et al., 2006).

Attention can also constrain perceptual organization (e.g., Freeman, Sagi, & Driver, 2001, 2004; Han, Jiang, Mao, Humphreys, & Gu, 2005; Han, Jiang, Mao, Humphreys, & Qin, 2005; Peterson & Gibson, 1994; Vecera, Flevaris, & Filapek, 2004). For example, Freeman et al. (2001) showed that detection of a central Gabor target was improved by flankers collinear with the target only when the flankers were attended to; when unattended these flankers did not interact with the target, as if they were not physically present in the display. Vecera et al. (2004) showed that when spatial attention is directed to one of the regions of an ambiguous figure-ground stimulus, the attended region is perceived as figure and the shared contour is assigned to the attended region. Whether perceptual organization can be accomplished without attention appears to depend on the type of perceptual organization and on the processes involved. For example, Kimchi and Razpurker-Apfeld (2004) showed that grouping elements into columns/rows by color similarity (see also, Russell & Driver, 2005; Shomstein, Kimchi, Hammer, & Behrmann, 2010) can take place without attention, whereas grouping elements into a shape by color similarity cannot, and figure-ground segmentation can occur under inattention when the cue is convexity (Kimchi & Peterson, 2008), but not when the cue is symmetry (Rashal, Kimchi & Yeshurun, in preparation).

The critical role of perceptual organization in structuring the visual information and designating potential objects raises another important issue concerning the interplay between perceptual organization and attention: Can perceptual organization affect the automatic, stimulus-driven deployment of attention? Assuming that the Gestalt organization factors and perhaps other non-accidental properties are likely to reflect environmental regularities, probabilistically implying objects in the environment (e.g., Driver et al., 2001), granting priority to a perceptual unit that conforms to Gestalt factors is a desirable characteristic for a system whose goal is to construct a meaningful representation of the environment, identify and recognize objects and act upon them.

Following this reasoning, Kimchi and colleagues (Kimchi, Yeshurun, & Cohen-Savransky, 2007; Yeshurun, Kimchi, Sha'shoua, & Carmel, 2009) examined whether the mere organization of some elements in the visual field into an object captures attention automatically, in a stimulus-driven manner.[1] Several previous studies, demonstrating object-based attentional effects, showed that attention can be deployed to an object (e.g., Egly et al., 1994; Kramer & Jacobson, 1991), but none of these studies showed unequivocally that the object per se was the factor that attracted attention, because there were always other factors that directed attention to a part or an attribute of the object, such as cuing or instructions.

In the study of Kimchi et al. (2007), observers were presented with an array of multiple *L* elements, a subset of which formed an object (a diamond-like configuration) on some trials (object trials) and no object on the other trials (No-object trials). The task was to report the color of a target, which was defined by its location relative to an asterisk (e.g., above or right to the asterisk). The asterisk appeared 150 ms following the onset of the elements array, and in the object trials, it could appear inside the object (Inside-object trials) or outside the object (Outside-object trials). The object was task irrelevant, not predictive of the target, and was not associated with unique abrupt onset or any other unique transient. Nonetheless, response times to the target on the object trials were faster when the asterisk appeared within the object and slower when the asterisk appeared outside the object; also, response times were faster in the Inside-object trials than in the No-object trials (benefit) and slower in the Outside-object trials than in the No-object trials (cost). These findings indicate that the object captured attention automatically, in a stimulus-driven manner.

In a further experiment (Yeshurun et al., 2009) we replicated the object effect when the target was not a part of the object and with simplified task demands. As in our previous study, observers were presented with an array of *L* elements, some of which formed an object on some trials. The target was a Vernier stimulus comprised of two vertical lines, one line appearing above the other and separated by a small horizontal offset, and the observers had to indicate the direction of the offset (left or right). Performance was faster and more accurate when the target appeared in the center of the object than in a non-object location, and this effect was observed even when the target appeared after the elements array disappeared, indicating automatic deployment of attention to the object, and suggesting the involvement of a spatial component.

Thus, our previous results (Kimchi et al., 2007; Yeshurun et al., 2009) demonstrate unequivocally that a perceptual object, in itself, can capture attention automatically. The current work addresses three core issues concerning this unique, perceptual organization-driven attentional capture.

(1) Does the attentional capture by a perceptual object involve a spatial component? Previous research has suggested that attentional selection can occur on the basis of spatial and object representations simultaneously (e.g., Egly et al., 1994; Kravitz & Behrmann, 2008; Vecera & Farah, 1994), and our pervious study (Yeshurun et al., 2009) suggested the involvement of a spatial component in the automatic deployment of attention to the object. The first study (Experiments 1a and 1b) is concerned with a further examination of this issue by investigating not only the presence of object effects after the disappearance of the object, but also the sensitivity of the object effect to spatial manipulations. To this end we used an array with a larger number of elements than in our previous studies and tested object effects and the effect of the distance between the target and the object on performance, both when the target and the object were present in the display simultaneously and when the target appeared after the object disappeared. To foreshadow, the results provided further converging evidence that a perceptual object captures attention automatically and that this

[1] What constitutes an object in visual perception has turned out to be a rather difficult question to answer (e.g., Feldman, 2003; Scholl, 2001). In our work we refer to an object as 'elements in the visual scene organized by Gestalt factors into a coherent unit'.