
ELSEVIER
VISION
RESEARCH
An International Journal for Functional Aspects of Vision
SPECIAL ISSUE
Visual Attention: Psychophysics, electrophysiology and neuroimaging
GUEST EDITORS
Marisa Carrasco Geoffrey Boynton, Stefan Treue, Preeti Verghese
Biochemistry & Cell Biology • Molecular Biology & Genetics
Anatomy, Physiology, Pathology & Pharmacology • Optics, Accommodation & Refractive Error
Circuitry & Pathways • Psychophysics • Perception • Attention & Cognition
Computational Vision • Eye Movements & Visuomotor Control
ISSN 0042-6989 | Volume 49 | Number 10 | 2 June 2009

Vision Research 49 (2009) 1329–1335

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

Perceptual objects capture attention

Yaffa Yeshurun *, Ruth Kimchi *, Guy Sha'shoua, Tomer Carmel

Department of Psychology, University of Haifa, Haifa 31905, Israel

ARTICLE INFO

Article history:
Received 3 October 2007
Received in revised form 25 December 2007

Keywords:
Visual attention
Attentional capture
Perceptual object
Perceptual organization
Automatic attentional deployment

ABSTRACT

A recent study has demonstrated that the mere organization of some elements in the visual field into an object attracts attention automatically [Kimchi, R., Yeshurun, Y., & Cohen-Savransky, A. (2007). Automatic, stimulus-driven attentional capture by objecthood. *Psychonomic Bulletin & Review, 14*(1), 166–172]. We tested whether similar results will emerge when the target is not a part of the object and with simplified task demands. A matrix of 16 black L elements in various orientations preceded the presentation of a Vernier target. The target was either added to the matrix (Experiment 1), or appeared after its offset (Experiment 2). On some trials four elements formed a square-like object, and on some of these trials the target appeared in the center of the object. No featural uniqueness or abrupt onset was associated with the object and it did not predict the target location or the direction of the target's horizontal offset. Performance was better when the target appeared in the center of the object than in a different location than the object, even when the target appeared after the matrix offset. These findings support the hypothesis that a perceptual object captures attention (Kimchi et al., 2007), and demonstrate that this automatic deployment of attention to the object is robust and involves a spatial component.

1. Introduction

The successful comprehension of the visual information we encounter requires both attentional processes that afford the selection of the relevant information out of the non-relevant information, and perceptual organization processes that structure the bits and pieces of visual information into larger entities that correspond to meaningful objects. In recent years, a growing body of evidence have demonstrated the close interplay between attentional and perceptual organization processes (e.g., Driver, Davis, Russell, Turatto, & Freeman, 2001; Scholl, 2001; Vecera, 2000). Several studies have demonstrated that attention can constrain perceptual organization. For instance, Freeman and colleagues provided evidence for attentional modulation of lateral interactions by showing that attention can modulate flanker-target integration (Freeman, Driver, Sagi, & Zhaoping, 2003; Freeman, Sagi, & Driver, 2001). Specifically, the detection of a central Gabor target was improved by the presence of collinear flankers when the collinear flankers were attended, but not when the collinear flankers were ignored in favor of flankers with orthogonal orientation. Kimchi and Razpurker Apfeld (2004) showed that some forms of grouping, such as grouping elements into columns/rows by color similarity (see also Russell & Driver, 2005) can take place without attention, whereas other forms of grouping, such as grouping elements into a shape by color similarity, require controlled attentional processing. Vecera and colleagues demonstrated that exogenous precue presented inside one of the regions of an ambiguous figure-ground stimulus can affect figure-ground assignment—the attended region is perceived as figure and the shared contour is assigned to the attended region (Vecera, Flevaris, & Filapek, 2004).

Other studies have demonstrated that various organizational processes constrain attentional selectivity (e.g., Davis & Driver, 1997; Driver & Baylis, 1998; Moore, Yantis, & Vaughan, 1998; Watson & Kramer, 1999). For example, responding to two features is easier when they belong to the same object than when they belong to two separate objects (e.g., Behrmann, Zemel, & Mozer, 1998; Duncan, 1984), and interference from distractor stimuli in selective attention tasks is greater when the target and distractors are strongly grouped by gestalt cues such as color similarity, good continuation, and closure (e.g., Baylis & Driver, 1992; Driver & Baylis, 1989; Kahneman & Henik, 1981; Kramer & Jacobson, 1991). Similarly, the cost associated with directing attention via spatial precues to a non-target location is smaller when the target location is on the same object as the cue location than when the target and cue appear on separate objects (e.g., Egly, Driver, & Rafal, 1994; Goldsmith & Yeari, 2003; Moore et al., 1998). Finally, neurophysiological studies have found that attended stimuli and unattended stimuli belonging to the same object elicited a very similar spatiotemporal pattern of enhanced neural activity in the visual cortex, even when the object were defined by illusory boundaries (Martínez, Ramanathan, Foxe, Javitt, & Hillyard, 2007a; Martínez, Teder-Sälejärvi, & Hillyard, 2007b; Martínez

* Corresponding authors. Fax: +972 4 8240966.
E-mail addresses: yeshurun@research.haifa.ac.il (Y. Yeshurun), rkimchi@research.haifa.ac.il (R. Kimchi).

0042-6989/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.visres.2008.01.014

et al., 2006). These various findings suggest that perceptual organization and visual attention mutually constrain one another.

In a recent paper, Kimchi, Yeshurun, and Cohen-Savransky (2007) have addressed another important aspect of the interplay between perceptual organization and attention. They have demonstrated that perceptual organization can affect the automatic, stimulus-driven deployment of attention. In that study they employed a display composed of nine red and green L elements rotated at different angles and forming the vertices of four adjacent quadrants that make up a global diamond. The observers' task was to report the color of one of the elements as indicated by an asterisk presented in the center of one of the quadrants and an instruction word—'above', 'below', 'right', or 'left'—that specified the position of the target relative to the asterisk. For instance, if the word was 'left', observers had to report the color of the element left to the asterisk. Each trial began with one of the instruction words, then the display appeared and the asterisk was added in the center of one of the four quadrants. Thus, performing the task requires locating the asterisk, then locating the target relative to the asterisk based on the instruction word, and analyzing the target's color. On half the trials, the four elements of one of the quadrants were collinear and therefore formed a local diamond—an "object". There were three critical 'object' conditions: *Inside-object:* The asterisk appeared in the object quadrant (a quarter of the trials with an object—12.5% of all trials); *Outside-object*: The asterisk appeared in a non-object quadrant, but an object was presented in another quadrant (three quarters of the trials with an object—37.5% of all trials); and *No-object*: The elements did not form an object in any quadrant (50% of all trials). The diamond-like object was irrelevant to the task at hand (because the task relevant feature was the color of a single element) and did not predict the relevant quadrant or the target. Moreover, because all the elements appeared simultaneously no abrupt onset was specifically associated with the object. That is, there was no top-down incentive for the observers to deliberately attend the object, nor was there any previously known stimulus-driven cue, such as feature-singleton, abrupt onset, or any other unique transient, to automatically attract attention to the object quadrant. Nevertheless, the results showed the expected cost and benefit demonstrating capture of attention by the irrelevant object: When an object was present in the display and the asterisk appeared in the object quadrant (Inside-object condition), the observers indicated the color of the target faster than when there was no object in the display (No-object condition), and when the asterisk appeared in a non-object quadrant (Outside-object condition), the observers needed more time to indicate the target color than in the No-object condition. These findings suggest that the object captured attention in a stimulus-driven fashion.

This is an unequivocal demonstration that the mere organization of some elements in the visual field into an object, that otherwise do not have any unique property (including abrupt onset or other unique transients), suffices to attract attention automatically. Previous studies that found object-based attentional effects have always employed endogenous or exogenous information, in addition to the presence of objects, to direct attention to the relevant object. For instance, some studies employed a brief flicker presented in one end of the relevant object to exogenously summon attention (e.g., Egly et al., 1994; Goldsmith & Yeari, 2003; Marino & Scholl, 2005; Moore et al., 1998; Pratt & Sekuler, 2001), and other studies used central cues, instructions, or task-related factors to encourage observers to direct their attention to one of the objects (e.g., Behrmann et al., 1998; Duncan, 1984; Martínez et al., 2006, 2007a, 2007b; Matsukura & Vecera, 2006; Watson & Kramer, 1999). Because other factors were always present, previous studies do not show that the object *per se* was the factor that attracted attention. In Kimchi et al.'s (2007) study there was no additional factor that may have attracted attention apart from the organization of some elements into an object, and therefore a stimulus-driven attentional capture by the object is the most likely interpretation of the cost and benefit effects found there. These findings suggest that the visual system favors perceptual unit that conforms to Gestalt factors such as closure and collinearity. Granting priority to coherent units is advantageous for a system whose goal is to construct a meaningful representation of the physical world because these coherent perceptual units are likely to imply meaningful objects in the environment.

Interestingly, in the Outside-object condition, in which the asterisk appeared in a non-object quadrant, the instruction word of some of the trials referred to a target-element that actually "belonged" to the object (i.e., one of the four elements forming an object in another quadrant) whereas instruction word of the other trials referred to a target-element that did not belong to the object. A separate analysis of the cost for these two types of trials showed costs for both types of trials with somewhat higher cost for target-elements that belonged to the object. This finding suggests that some of the observed cost may be also attributed to difficulty in "extracting" an element that was already grouped into an object. Thus, the attentional effects we observed in Kimchi et al. (2007) might be due to a mixture of attentional related processes and other processes that are not necessarily related to attention but to the actual processing of the object (e.g., grouping the elements into an object, extracting an element from an object, etc.). In this study we ask whether a similar automatic attraction of attention will be found even when the target is not a part of the object and task demands are not high. In a neurophysiological study, Senkowski and colleagues asked the participants to indicate whether a small triangle was pointing to the left or right (Senkowski, Rottger, Grimm, Foxe, & Herrmann, 2005). Prior to the target presentation a display of 23 inducers disks was presented, and on 2/3 of the trials this display included a Kanizsa triangle, appearing in one of two possible locations. On half of trials with a Kanizsa figure the target appeared within the Kanizsa figure, and on the other half it appeared at the other location. Hence, the Kanizsa figure did not predict the target location. The finding that response times were significantly faster when the target appeared within the Kanizsa figure than at the other location seems to suggest that the Kanizsa figure captured attention automatically to its location. This would imply that an automatic attraction of attention to an object occurs even when the target is not a part of the object. However, given that both the Kanizsa figure and the target were triangles it is possible that the attentional capturing by the Kanizsa figure reflects a controlled search for a triangle rather than a truly spontaneous deployment of attention to the object.

The current study was designed to examine whether attentional effects that are due to an automatic attraction of attention by the object can be found with displays in which the target is never a part of the object, has no figural resemblance to the object, and with simplified task demands. The color identification task employed in Kimchi et al. was replaced with a task that measures Vernier resolution. The target in this task was a Vernier target composed of two vertical lines with one line appearing above the other and was separated by a small horizontal offset. The observers had to indicate whether the upper line was displaced to the left or right of the lower line. We have chosen this task because it was already shown that when attention is directed to the location of a Vernier target, via onset precues, observers are faster and more accurate in this task (Yeshurun & Carrasco, 1999). Additionally, this task does not involve the relatively high memory load that was involved in the Kimchi et al.'s task. Prior to the presentation of the target, a matrix of 16 black L elements in various orientations was presented to the observers (Fig. 1a). On half of the trials, four elements were collinear, forming an object—a square

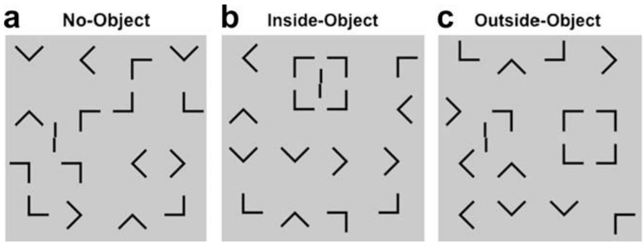

Fig. 1. Examples of the displays in the three conditions of Experiment 1: No-object condition, no object is present in the display; Inside-object condition, an object is present in the display and the Vernier target appears in the center of the object; and Outside-object condition, an object is present in the display but the Vernier target appears in a different location. Fifty percent of the trials were No-object trials, 12.5% were Inside-objects trials, and 37.5% were Outside-object trials.

(Fig. 1b and c). There were four possible locations in which the object could appear. On one quarter of the trials with an object (12.5% of total trials) the Vernier target appeared at the center of the object (*Inside-object* condition, Fig. 1b). On three quarters of the trials with an object (37.5% of total trials) the Vernier target appeared at one of the other three possible locations (*Outside-object* condition, Fig. 1c). On the rest of the trials (50% of total trials) the elements did not form an object, and the target appeared in one of the four possible locations (*No-object* condition, Fig. 1a). Thus, this matrix is completely irrelevant for the task and the object is not predictive of the target location or the direction of offset. Moreover, the Vernier target is never a part of the object. If attention is automatically attracted to the square formed by the elements, and its effects do not depend on the target being part of the square or on the complexity of the task demands, then performance should be affected by the presence of the square and the location of the target relative to the location of the square.

To ensure that indeed no featural uniqueness is associated with the square-like object, we used the SaliencyToolbox (Walther & Koch, 2006) to compute saliency maps of our matrix display. These saliency maps represent the featural conspicuity at every location in the visual scene. To compute these saliency maps the images are first decomposed into a set of 'feature maps', which encode local spatial discontinuities in color, intensity, and orientation. Then, these features maps are combined in a purely bottom-up manner into a saliency map (e.g., Itti & Koch 2000; Itti, Koch, & Niebur, 1998). If the square-like object in our displays includes any featural saliency, at least based on one of these three features, then this saliency should be evident in the saliency maps created for our displays. Fig. 2 presents 4 randomly chosen examples of matrices with an object, and their corresponding saliency map (lighter regions in the saliency map are more salient). As can be clearly seen, there is no consistent high saliency associated with the object. To evaluate the featural saliency of the square-like object in our displays in a more quantitative fashion we randomly generated 48 matrices that include an object, and used the SaliencyToolbox to find the L element with of highest saliency value. Because each matrix is composed of 16 L elements of which 4 belong to the object, the probability of choosing an L element that belongs to the object by chance is 0.25. Hence, if the L elements that belong to the object are not more salient than the other L elements they should have the highest saliency value on no more than 25% of the matrices. Indeed, an L element that belonged to the object had the highest saliency value on 11 out of 48 matrices. Thus, if evidence of attentional attraction to the object is found it cannot be attributed to featural saliency.

2. Experiment 1

2.1. Method

2.1.1. Observers

Nine observers with normal or corrected-to-normal vision participated in this experiment.

2.1.2. Stimuli

The elements matrix ($12° \times 12°$) included 4×4 black L elements presented on a gray background (Fig. 1). Each arm of the L element subtended $1.2° \times 0.15°$, and unless the L element was part of an object it was pseudo-randomly rotated to one of 8 possible angles (0°, 45°, 90°, 135°, 180°, 225° 270°, 315°). That is, the orientation of each element was chosen randomly from one of these eight orientations, but if the chosen orientation violated one of several constraints ensuring that no object was randomly formed, another orientation was randomly chosen until all constraints were satisfied. The distance between the corner of one L element to another was 3°.

The Vernier target was composed of two $0.84° \times 0.15°$ vertical, black lines. One of the lines appeared 0.03° above the other line and was 0.09° horizontally offset to the left or right of the lower line. There were four possible target locations, each at 3° of eccentricity, and the target appeared equally often at each location.

There were three critical object conditions. In the Inside-object condition (12.5% of total trials), four elements were rotated to form a square-like shape, and the target was presented in the center of the square (Fig. 1b). In the outside-object condition (37.5% of total

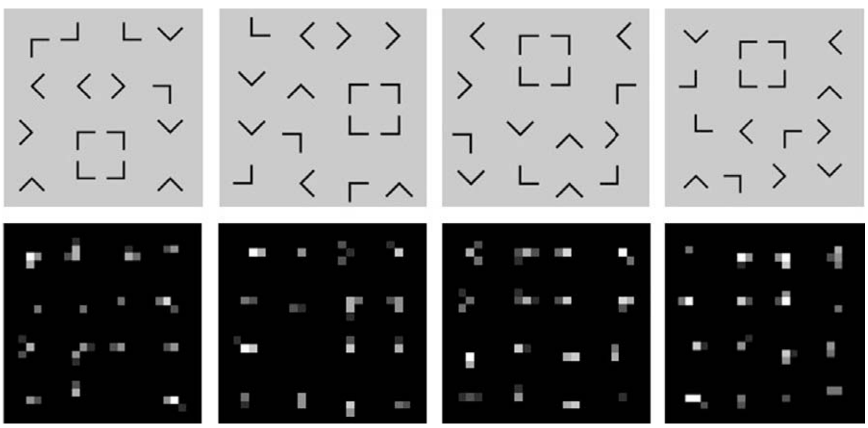

Fig. 2. Randomly chosen examples of matrices with an object (upper row) and their corresponding saliency maps (lower row). The lighter a region in the saliency map is, the higher its saliency.

trials), four elements were also rotated to form a square-like shape, but the target was presented in one of the other three possible locations outside the square (Fig. 1c). Finally, in the no-object condition (50% of total trials) the elements did not form any object and the target appeared in one of the four possible locations (Fig. 1a).

2.1.3. Procedure

Each trial began with a fixation dot appearing for 500-ms and followed by the elements matrix. 150-ms after the onset of the matrix the target appeared and stayed on until response. The observers had to indicate, as fast and accurately as possible, whether the upper line of the target was offset to the right or left of the lower line. Each observer participated in 64 practice trials and 2880 experimental trials administrated in three 1-h sessions.

2.2. Results and discussion

A one-way (object condition: Inside-objects, Outside-object, No-object) repeated-measures ANOVA was performed on mean correct response times (RT) and error rates data. For the RT data, the ANOVA revealed a significant effect of object [$F(2,16) = 5.48$, $MSE = 34.24$, $p < .02$, $\eta_p^2 = 0.41$]. As can be seen in Fig. 3a, the observers made the fastest responses when the target appeared in the center of the square (Inside-object condition) and the slowest responses when the target appeared in a different location than the square (Outside-object condition). Planned comparisons revealed that the observers were indeed significantly faster in the Inside-object condition than in the Outside-object condition [$F(1,8) = 6.17$, $MSE = 60.09$, $p < .04$, $\eta_p^2 = 0.44$]. In addition, the cost in RT—slower responses in the Outside-object than in the No-object conditions—was statistically significant [$F(1,8) = 8.1$, $MSE = 16.05$, $p < .03$, $\eta_p^2 = 0.5$], but the benefit in RT—faster responses in the Inside-object than in the No-object condition—although in the right direction, did not reach statistical significance [$F(1,8) = 2.32$, $MSE = 26.57$, $p = .166$].

A significant effect of object was also found for the error rates data [$F(2,16) = 5.66$, $MSE = 0.33$, $p < .02$, $\eta_p^2 = 0.42$]. The pattern of results for the error rates data is presented in Fig. 3b and it evidently corresponds to that of the RT: the observers made the least errors when the target appeared in the center of the square and had the highest error rate when the target appeared in a different location than the square. This pattern of results was confirmed by planned comparisons showing that the observers made significantly less errors in the Inside-object condition than in the Outside-object condition [$F(1,8) = 8.37$, $MSE = 0.43$, $p < .02$, $\eta_p^2 = 0.51$]. Finally, the cost and benefit in error rates were marginally significant [cost: $F(1,8) = 4.42$, $MSE = 0.088$, $p = .07$, $\eta_p^2 = 0.36$; benefit: $F(1,8) = 3.43$, $MSE = 0.48$, $p = .1$, $\eta_p^2 = 0.3$].

These results demonstrate that the presence of an object in the display affected the ability of the observers to discriminate the offset direction of the Vernier target. They are consistent with Senkowski et al.'s (2005) finding of a facilitated discrimination of targets appearing within a Kanizsa figure, but unlike that study, the object in this experiment did not resemble the target and therefore could not attract attention based on such resemblance. Given that the object was not relevant for the task and that there was no uniqueness associated with the elements that formed the object, apart for their perceptual organization, these findings support the proposition that the mere organization of elements into an object attracts attention automatically (Kimchi et al., 2007). Furthermore, these findings demonstrate that this automatic attraction of attention to an object is robust and does not depend on the relevant information being a part of the object or on the involvement of high memory load.

The main difference between the results of this experiment and our previous study (Kimchi et al., 2007) is that the benefit in RT did not reach statistical significance. This finding is further explored in Experiment 2.

3. Experiment 2

The findings of Experiment 1 clearly indicate that the organization of the elements into an object affected performance. However, in contrast to our previous findings in which the target was a part of the object (Kimchi et al., 2007), the performance benefit—better performance in the Inside-object than No-object condition—was not statistically significant. Hence, when the target could be a part of the object, both significant effects of benefit and cost were found (Kimchi et al., 2007), but when the target was never a part of the object, only the cost was statistically significant (Experiment 1). This lack of significant attentional benefit appears to be consistent with a recent finding by Nelson and Palmer (2007). They employed bipartite figure-ground displays and presented targets equally often on both sides of the central contour. They found that the detection and discrimination of targets were facilitated when these targets appeared on the figure side rather than the ground side, but only when the targets were presented close to the contour. When the targets were presented on the figure side but not close

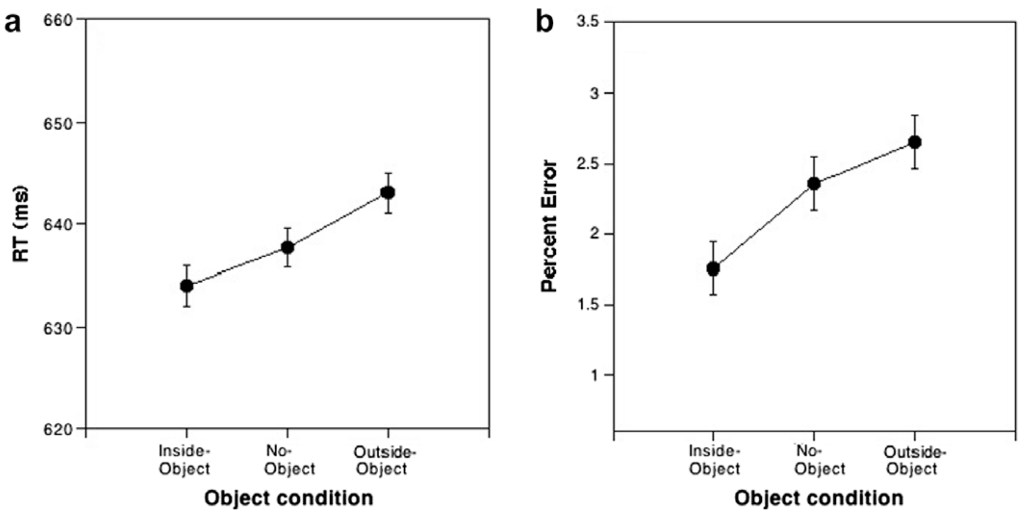

Fig. 3. (a) Mean correct RTs and (b) error rates as a function of object condition in Experiment 1.

to the contour there was no figural advantage. Nelson and Palmer (2007) suggested that this finding indicates that attention is mainly allocated to the contours of the figure.

Thus, one possible interpretation of the different patterns of results in Experiment 1 vs. Kimchi et al. (2007) is as follows. When attention is attracted to the object and the target is an integral part of the object, the processing of the target can obviously benefit from the allocation of attention to the object. Yet, when the target is not an integral part of the object and attention is attracted to the object, there is a competition over resources between the target and the object. Such competition may 'dilute' the advantage of the advanced allocation of attention to the target brought about by the attentional attraction to the object, resulting in a smaller benefit than that observed when there is no competition. This interpretation is especially viable if attention is indeed allocated to the contours of the object (Nelson & Palmer, 2007), and it is consistent with the finding that responding to two features is easier when the features belong to the same object than when they belong to two separate objects (e.g., Baylis & Driver, 1993; Behrmann et al., 1998; Duncan, 1984; Vecera & Farah, 1994). This two-object disadvantage is typically attributed to the need to switch attention between the two objects. Although in Experiment 1 there was no need to respond to any aspect of the square, it seems to automatically attract attention, resulting in a need for attentional switch when the Vernier target appears.

Experiment 2 was designed to test the hypothesis that the lack of significant attentional benefit in Experiment 1 was due to a competition between the object and target. To that end, the experimental paradigm employed in this experiment is very similar to that employed in Experiment 1 apart for the fact that the matrix of elements disappears before the onset of the Vernier target. Thus, in contrast to Experiment 1, when the Vernier target appears, it is the only entity present in the display and therefore there is no competition over resources, or a need for attentional switch. If the lack of significant attentional benefit in Experiment 1 was indeed due to such competition, a significant benefit should emerge in this experiment as there is no longer any competition.

3.1. Method

3.1.1. Observers

Eight observers with normal or corrected-to-normal vision participated in this experiment; none of them participated in Experiment 1.

3.1.2. Stimuli and procedure

The stimuli and procedure were identical to those in Experiment 1 apart for the fact that the elements matrix disappeared 100-ms after its onset, and 50-ms after the offset of the matrix the Vernier target was presented until response.

3.2. Results and discussion

A one-way (object condition: Inside-objects, Outside-object, No-object), repeated-measures ANOVA, was performed on mean correct RT and error rates data. Similar to Experiment 1, a significant effect of object emerged for the RT data [$F(2,14) = 12.49$, $MSE = 30.17$, $p < .001$, $\eta_p^2 = 0.64$], and as can be seen in Fig. 4a, the pattern of results in this experiment replicated those of Experiment 1: The fastest responses were made when the target appeared in the center of the square (Inside-object condition), and the slowest responses were made when the target appeared in a different location than the square (Outside-object condition). Planned comparisons confirmed that the observers were indeed significantly faster in the Inside-object condition than in the Outside-object condition [$F(1,7) = 18.65$, $MSE = 40.08$, $p < .004$, $\eta_p^2 = 0.73$]. Additionally, the cost in RT was statistically significant [$F(1,7) = 6.27$, $MSE = 21.10$, $p < .04$, $\eta_p^2 = 0.47$], and most importantly, the benefit in RT was also statistically significant [$F(1,7) = 8.55$, $MSE = 29.35$, $p = .03$, $\eta_p^2 = 0.55$].

The error rate data showed similar effects to those of the RT data (Fig. 4b), but they did not reach statistical significance, apart for the comparison between the Inside-object condition and the Outside-object condition, which was marginally significant [$F(1,7) = 3.31$, $MSE = 0.33$, $p = .1$, $\eta_p^2 = 0.32$]; observers made less errors in the Inside-object than the Outside-object conditions.

Thus, similarly to Experiment 1 and our previous study (Kimchi et al., 2007), performance in this experiment was affected by the presence of the object. These findings provide further support to the conclusion that attention is automatically attracted to the object, because they demonstrate object effects on performance even when the target and square do not appear together. Most relevant to the purpose of this experiment, once the square and target were not present in the display simultaneously, a significant benefit emerged. This finding suggests that the lack of such benefit in Experiment 1 was due to a competition between the square and target. Specifically, when both the object and the target were present in the display, and the target was not a part of the object (Experiment 1), there was a competition between the target and

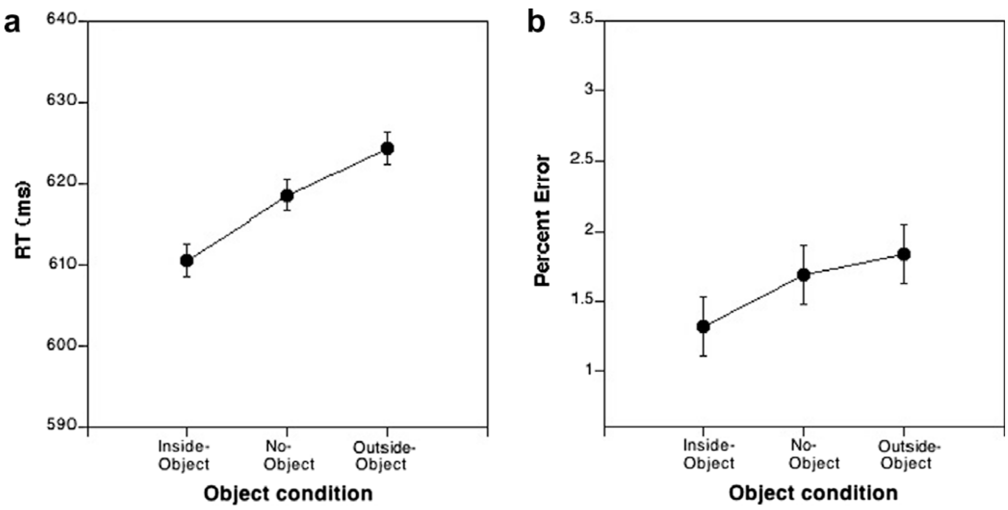

Fig. 4. (a) Mean correct RTs and (b) error rates as a function of object condition in Experiment 2.

the object over attentional resources, which might have required an attentional switch from the object to the target. This might have attenuated the performance benefit due to the advanced allocation of attention to the target location. In contrast, when the target appeared after the offset of the object (Experiment 2) there was no competition over attentional resources or a need for attentional switch and the performance benefit was not attenuated.

4. General discussion

The goal of this study was to test the robustness of Kimchi et al.'s (2007) finding that the mere organization of some elements into an object attracts attention automatically to the object. Specifically, this study tested whether evidence of automatic attentional attraction to an object will be found even when the target is not a part of the object and memory load is low. We performed two experiments in which the elements display preceded the presentation of a Vernier target. On some of the trials four elements formed a square-like object, and on some of these trials the target appeared in the center of the object. Importantly, the object was not relevant to the task at hand (discriminating the offset direction of the Vernier target), did not resemble the target, and was not predictive of the target location. Additionally, there was no featural uniqueness, abrupt onset, or any kind of unique transient associated with the object or the elements. This ensured that none of the factors known to capture attention, apart for the presence of an object, could account for any attentional effects found. Similar to previous studies (Kimchi et al., 2007; Senkowski et al., 2005), the presence of an object in the elements display affected performance in both experiments. Performance was better when the target appeared in the center of the object (Inside-object condition) than in a different location than the object (Outside-object condition). These findings provide corroborating evidence in support of the hypothesis that attention is automatically attracted to the object, and indicate that this attentional capturing is robust and does not depend on high memory load or on the target being a part of the object.

The finding of an automatic capture of attention by the object is consistent with the results of Nelson and Palmer (2007) which demonstrated that attention was automatically attracted to the figural side of bipartite figure-ground displays. Hence, attention seemed to be automatically attracted to a figure just as it seemed to be automatically attracted to the object in our study, indicating the influence of perceptual organization on automatic deployment of attention.

Additionally, an automatic attraction of attention by an object may account for a variety of 'object-superiority' effects, which demonstrate the perceptual advantage of objects over unorganized elements (e.g., Arrington, Carr, Mayer, & Rao, 2000; Driver & Baylis, 1996; Gorea & Julesz, 1990; Kovacs & Julesz, 1993; Weisstein & Harris, 1974; Womersley, 1977; Wong & Weisstein, 1982). For instance, Arrington and colleagues (Arrington et al., 2000) found greater brain activation when the target appeared in a region bounded by an object than when it appeared in an unbounded region, and Driver and Baylis (1996) found better memory for contours associated with the figure than for contours associated with the ground. Likewise, Wong and Weisstein (1982) found that the discrimination of a line segment was easier when it was presented on the region perceived as the figure than on a region perceived as the ground, Gorea and Julesz (1990) have shown that the detection of four target lines embedded in distractors lines was easier when the target lines were organized into a face-like pattern than a meaningless cluster, and Kovacs and Julesz (1993) found higher sensitivity for a target probe when positioned inside a circular contour embedded in a random background rather than outside the circle. This body of studies demonstrated the special status of objects in our visual system, but they did not offer the mechanism underlying this 'object advantage'. Here we suggest that the automatic, stimulus-driven, deployment of attention to objects can explain the facilitated processing of objects demonstrated in these studies.

The performance benefit that emerged in Experiment 2, when the Vernier target appeared after the offset of the elements display suggests that the automatic attraction of attention by the object was, at least partially, mediated by spatial factors. That is, because the target was not a part of the object and did not appear at the same time with the object, it only shared its location with the object in the Inside-object condition, and therefore the performance benefit in this condition suggests that the deployment of attention to the object is mediated, or simply accompanied, by a deployment of attention to the object location. This finding is consistent with Kim and Cave's (2001) study in which observers were required to respond to spatial probes while also identifying a cued target letter among distractors. They found that probe responses were faster when the probe appeared at locations occupied by distractors with the target color than at locations occupied by distractors with the non-target color. According to Kim and Cave (2001), this finding suggests that the attentional selection may ultimately be based on location even when attention is directed by non-spatial properties such as grouping by color. Our finding of performance benefit in the Inside-object condition for targets that appeared after the elements matrix disappeared is also consistent with Kramer, Weber, and Watson's (1997) study. In that study observers were presented with two objects, a box and a line, and they had to judge two properties that could be located on either a single object or distributed between the two different objects. In addition, on some of the trials they had to respond to a post-display probe presented after the offset of the objects. Kramer et al. found that their observers responded more rapidly to the post-display probes when they occurred at a location previously occupied by an object that included both target properties. They interpreted their findings as strong evidence that the selection of object was location-mediated. These previous studies and our current study suggest, therefore, that even when attention is deployed to non-spatial aspects of the display, at least part of such attentional selection is mediated by spatial factors. That is, in addition to the selection of non-spatial properties such as objects with a specific color or a group of elements that conform to certain organization principles, there is also a selection of the spatial region occupied by the selected object. The selection of location may be the basis for the selection of the non-spatial property or it may simply accompany the non-spatial selection. Presumably, the selection of the spatial region occupied by the object did not suffice to overcome the competition between the object and the target (Experiment 1), but in the absence of such competition, the effect of spatial selection surfaced.

Finally, a performance cost—worse performance in the Outside-object condition than in the No-object condition—was observed in both experiments. This cost may be due to the need to disengage attention from the object and redirect it to the actual location of the target, or it may be attributed to an attentional inhibition of information presented in non-attended areas. The finding of a performance cost in Experiment 2, when the target appears after the offset of the elements display, suggests that at least part of the cost is due to attentional inhibition of non-attended locations, because when the target is presented, in this experiment, there is no other information present and therefore there is no need for attentional disengagement or redirection.

In sum, this study demonstrates that the mere organization of some elements into an object suffices to automatically attract attention to the object (Kimchi et al., 2007). Moreover, because the target was not a part of the object, and because attentional effects were found even when the target appeared after the offset of the elements, the results of this study suggest that this automatic deployment of attention to the object involves a spatial component. Whether the attentional selection is exclusively space-based or some combination of object-based and space-based components awaits future research.

Acknowledgments

This research was supported by Israel Science Foundation Grant 94/06 to R.K. and Y.Y. We thank Michal Rovner and Allegra Dan for help in data collection.

References

Arrington, C.-M., Carr, T.-H., Mayer, A.-R., & Rao, S.-M. (2000). Neural mechanisms of visual attention: Object-based selection of a region in space. *Journal of Cognitive Neuroscience, 12*(Suppl 2), 106–117.

Baylis, G. C., & Driver, J. (1992). Visual parsing and response competition: The effect of grouping factors. *Perception and Psychophysics, 51*(2), 145–162.

Baylis, G. C., & Driver, J. (1993). Visual attention and objects: Evidence for hierarchical coding of location. *Journal of Experimental Psychology: Human Perception and Performance, 19*, 451–470.

Behrmann, M., Zemel, R. S., & Mozer, M. C. (1998). Object-based attention and occlusion: Evidence from normal participants and a computational model. *Journal of Experimental Psychology: Human Perception and Performance, 24*(4), 1011–1036.

Davis, G., & Driver, J. (1997). Spreading of visual attention to modally versus amodally completed regions. *Psychological Science, 8*(4), 275–281.

Driver, J., & Baylis, G. (1996). Edge-assignment and figure-ground segmentation in short-term visual matching. *Cognitive Psychology, 31*, 248–306.

Driver, J., & Baylis, G. C. (1989). Movement and visual attention: The spotlight metaphor breaks down. *Journal of Experimental Psychology: Human Perception and Performance, 15*, 448–456.

Driver, J., & Baylis, G. C. (Eds.). (1998). *Attention and visual object segmentation*. Cambridge, MA, USA: The MIT Press.

Driver, J., Davis, G., Russell, C., Turatto, M., & Freeman, E. (2001). Segmentation, attention and phenomenal visual objects. *Cognition, 80*(1–2), 61–95.

Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General, 113*(4), 501–517.

Egly, R., Driver, J., & Rafal, R. (1994). Shifting visual attention between objects and locations: Evidence from normal and parietal lesion subjects. *Journal of Experimental Psychology: General, 123*, 161–177.

Freeman, E., Driver, J., Sagi, D., & Zhaoping, L. (2003). Top-down modulation of lateral interactions in early vision: Does attention affect integration of the whole or just perception of the parts? *Current Biology, 13*(11), 985–989.

Freeman, E., Sagi, D., & Driver, J. (2001). Lateral interactions between targets and flankers in low-level vision depend on attention to the flankers. *Nature Neuroscience, 4*(10), 1032–1036.

Goldsmith, M., & Yeari, M. (2003). Modulation of object-based attention by spatial focus under endogenous and exogenous orienting. *Journal of Experimental Psychology: Human Perception and Performance, 29*(5), 897–918.

Gorea, A., & Julesz, B. (1990). Context superiority in a detection task with line-element stimuli: A low-level effect. *Perception, 19*(1), 5–16.

Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research, 40*, 1489–1506.

Itti, L., Koch, C., & Niebur, E. (1998). A model of saliency-based visual attention for rapid scene analysis. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 20*(11), 1254–1259.

Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In *Perceptual organization* (pp. 181–211). Hillsdale, NJ: Lawrence Erlbaum Associates.

Kim, M. S., & Cave, K. R. (2001). Perceptual grouping via spatial selection in a focused-attention task. *Vision Research, 41*(5), 611–624.

Kimchi, R., & Razpurker Apfeld, I. (2004). Perceptual grouping and attention: Not all groupings are equal. *Psychonomic Bulletin and Review, 11*(4), 687–696.

Kimchi, R., Yeshurun, Y., & Cohen-Savransky, A. (2007). Automatic, stimulus-driven attentional capture by objecthood. *Psychonomic Bulletin & Review, 14*(1), 166–172.

Kovacs, I., & Julesz, B. (1993). A closed curve is much more than an incomplete one: Effect of closure in figure-ground segmentation. *Proceedings of the National Academy of Sciences of the United States of America, 92*, 7495–7497.

Kramer, A. F., & Jacobson, A. (1991). Perceptual organization and focused attention: The role of objects and proximity in visual processing. *Perception and Psychophysics, 50*, 267–284.

Kramer, A. F., Weber, T. A., & Watson, S. E. (1997). Object-based attentional selection—Grouped-arrays or spatially-invariant representations? Comment on Vecera and Farah (1994). *Journal of Experimental Psychology: General, 126*, 3–13.

Marino, A. C., & Scholl, B. J. (2005). The role of closure in defining the "objects" of object-based attention. *Perception and Psychophysics, 67*(7), 1140–1149.

Martínez, A., Ramanathan, D. S., Foxe, J. J., Javitt, D. C., & Hillyard, S. A. (2007a). The role of spatial attention in the selection of real and illusory objects. *The Journal of Neuroscience, 27*(30), 7963–7973.

Martínez, A., Teder-Sälejärvi, W. A., & Hillyard, S. A. (2007b). Spatial attention facilitates selection of illusory objects: Evidence from event-related potentials. *Brain Research, 1139*, 143–152.

Martínez, A., Teder-Sälejärvi, W. A., Vasquez, M., Molholm, S., Foxe, J. J., Javitt, D. C., et al. (2006). Objects are highlighted by spatial attention. *Journal of Cognitive Neuroscience, 18*(2), 298–310.

Matsukura, M., & Vecera, S. P. (2006). The return of object-based attention: Selection of multiple-region objects. *Perception and Psychophysics, 68*(7), 1163–1175.

Moore, C., Yantis, S., & Vaughan, B. (1998). Object-based visual selection: Evidence from perceptual completion. *Psychological Science, 9*(2), 104–110.

Nelson, R. A., & Palmer, S. E. (2007). Familiar shapes attract attention in figure-ground displays. *Perception and Psychophysics, 69*, 382–392.

Pratt, J., & Sekuler, A. B. (2001). The effects of occlusion and past experience on the allocation of object-based attention. *Psychonomic Bulletin and Review, 8*(4), 721–727.

Russell, C., & Driver, J. (2005). New indirect measures of "inattentive" visual grouping in a change-detection task. *Perception and Psychophysics, 67*(4), 606–623.

Scholl, B. J. (2001). Objects and attention: The state of the art. *Cognition, 80*(1–2), 1–46.

Senkowski, D., Rottger, S., Grimm, S., Foxe, J. J., & Herrmann, C. S. (2005). Kanizsa subjective figures capture visual spatial attention: Evidence from electrophysiological and behavioral data. *Neuropsychologia, 43*, 872–886.

Vecera, S. P. (2000). Toward a biased competition account of object-based segregation and attention. *Brain and Mind, 1*, 353–384.

Vecera, S., & Farah, M. J. (1994). Does visual attention select objects or locations? *Journal of Experimental Psychology: Human Perception and Performance, 123*(2), 1–14.

Vecera, S. P., Flevaris, A. V., & Filapek, J. C. (2004). Exogenous spatial attention influences figure-ground assignment. *Psychological Science, 15*(1), 20–26.

Walther, D., & Koch, C. (2006). Modeling attention to salient proto-objects. *Neural Networks, 19*, 1395–1407.

Watson, S. E., & Kramer, A. F. (1999). Object-based visual selective attention and perceptual organization. *Perception & Psychophysics, 61*, 31–49.

Weisstein, N., & Harris, C. S. (1974). Visual detection of line segments: An object-superiority effect. *Science, 186*(4165), 752–755.

Womersley, M. (1977). A contextual effect in feature detection with application of signal detection methodology. *Perception and Psychophysics, 21*(1), 88–92.

Wong, E., & Weisstein, N. (1982). A new perceptual context-superiority effect: Line segments are more visible against a figure than against a ground. *Science, 218*, 587–589.

Yeshurun, Y., & Carrasco, M. (1999). Spatial attention improves performance in spatial resolution tasks. *Vision Research, 39*(2), 293–306.