Attentional Selection and the Representation of Holes and Objects

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Abstract

We examine whether holes (two separate cutout rectangles in a surface) appearing as if on a homogeneous background produce object-based effects similar to those observed when the same regions appear as separate items in front of that surface (commonly called objects). We used a version of the two-rectangle design described by Egly, Driver and Rafal (1994). Viewing modified patterns through stereoscopic goggles created the perception of the rectangles as either part of the background or as foreground objects. In Experiment 1, we replicated Egly et al. when the regions were perceived as objects but not when they were perceived as holes. In Experiment 2, we included a condition where the background was split: the rectangles in the holes condition were perceived as part of two separate background regions. In this case, the object-based effects were the same as when the rectangles were foreground objects. The findings of Experiment 2 demonstrate that those of Experiment 1 were not due to depth per se, but rather to the background being treated as a single region. More importantly, these results demonstrate that identically shaped regions in the stimulus engage object-based attention differently, depending on how the regions are perceptually organized.

Keywords

Attention; Object Perception; Perceptual Organization; Cueing; Depth Perception

Introduction

The perception of holes (cutouts in a surface) has generated a great deal of discussion in the literature on figure-ground organization (see Bertamini, 2006; Palmer, 1999 for review and discussion). Holes present a unique case in the study of figure-ground organization because they exhibit Gestalt qualities that are figural (e.g., smaller region, symmetry, closure), and yet they are perceptually organized as belonging to a background. Enclosed regions are more likely to be perceived as holes when occluded by a foreground surface, when comprised of relatively simple shapes, or when the enclosed region is similar (e.g., in texture, color, etc.) to that of a surface extending beyond the immediately surrounding region (Nelson & Palmer, 2001).

Much of the discussion surrounding holes concerns whether holes have shape or not (Bertamini & Croucher, 2003). Researchers have investigated whether and under what conditions a hole has shape (Bertamini & Croucher, 2003; Hulleman & Humphreys, 2005; Nelson & Palmer, 2001). Bertamini and Croucher (2003) proposed that the shape belongs, not to the hole, but to the surrounding region (see also Bertamini, 2006). They were able to manipulate a bias in judging relative heights of concave vs. convex vertices depending on whether a region was perceived as an object or a hole. However, other evidence suggests that under certain conditions, holes do have shapes. Rock, Palmer and Hume (cited in Palmer, 1999) found that the shapes of holes were remembered as well as were the shapes of figures. Furthermore, various researchers (e.g., Bertamini & Lawson, 2006; Hulleman & Humphreys, 2005) have demonstrated that participants are able to perform visual search for target regions that are either holes or objects. Although the question of whether holes have shape or not remains unresolved, the shape of the boundary of holes has an undeniable psychological reality.

The present set of experiments addresses how perceptual representation of regions as holes or as objects influences the deployment of visual attention. Critically, addressing this issue does not depend on the resolution of whether or not the holes or their surrounding region have shapes. Instead, we ask whether visual attention operates on an enclosed region differently when that region is perceived either as two separate entities (i.e., objects) or as two holes (i.e., part of the background). Nevertheless, if holes do have shape, then two separate holes should be perceived as two separate regions, and attention should be influenced by region boundaries in a similar way as to when the boundaries define foreground regions.

There is an expansive literature on selective attention to objects using procedures introduced by Egly, Driver and Rafal (1994) that shows that objects in a display modulates the allocation of attention (e.g., Atchley & Kramer, 2001; Haimson & Behrmann, 2001; Marino & Scholl, 2005; Moore & Fulton, 2005; Moore, Yantis, & Vaughn, 1998; Robertson & Kim, 1999; Scholl, 2001; Vecera, 1994). Egly et al. examined attentional selection by presenting two rectangles of equal length and distance from each other. They combined this stimulus with a Posner cuing task (Posner, Snyder, & Davidson, 1980) in which a cue predicted the location where a subsequent target would most likely appear. In a predictive cuing procedure Egly et al. cued one end of one of the rectangles and measured participants' reaction time (RT) to detect a target that appeared 300 ms later either at the cued location, at an uncued location within the same rectangle or at an equally distant uncued location within the uncued rectangle. As expected, RTs to cued locations were faster than those to uncued locations. The novel finding was from trials when targets appeared at uncued locations (invalid trials): RTs were faster when the target appeared in the cued rectangle (invalid-within object trials) than in the uncued rectangle (invalid-between objects trials) (Figure 1). Because the distances between the cued (valid) and each uncued (invalid) locations were spatially equivalent, the RT advantage for within compared to between rectangle conditions has been referred to as an object-based attention effect[1]. This procedure has been widely adopted to explore the roles of exogenous vs. endogenous attention (e.g., Jordan & Tipper, 1999; Macquistan, 1997) and hemispheric asymmetries (e.g., Egly, Rafal, Driver, & Starrveldt, 1994), among numerous other questions. However, given the above discussion on holes (namely, that all enclosed regions need not be objects), the "object" in object-based attention can be difficult to systematically define.

Several investigators have explored stimulus factors that produce object-based effects. One important line of research of great relevance to the current studies, examines whether perceptual completion affects object-based selection. Using a similar Egly et al. design, Moore, Yantis and Vaughn (1998) found an object-based advantage to unoccluded areas of rectangles which

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[1]By convention we will use the term "'object-based' effect" to refer to the RT benefit of the invalid-within over the invalid-between target locations.

were perceptually completed behind an occluder, i.e., when there was amodal completion. They found similar effects using stimuli that produced illusory contours of two rectangles, i.e., when there was modal completion. Other investigations using amodally completed rectangles have tested the role of previous experience on object-based attention (Pratt & Sekuler, 2001), and whether attention spreads to the occluded portions of completed objects (Davis & Driver, 1997; Moore & Fulton, 2005; Moore et al., 1998).

In the current studies, we consider whether an enclosed region is sufficient to elicit object-based effects, or whether the region must be perceived as an individuated object to do so. Using stereoscopic goggles and the Egly et al. design, the same enclosed regions can be presented in a way that makes them more likely to be perceived as an object or as a hole (i.e., part of a homogeneous background).

Experiment 1

In Experiment 1, depth cues were used to facilitate the perceptual organization of the two rectangular regions as either holes or objects or holes. Stereoscopic goggles were used to disambiguate the depth planes. We opted for a discrimination task, instead of the detection task used by Egly et al. (1994), as discrimination increases the magnitude of the object-based effects (see Brawn & Snowden, 2000). If attention is directed by enclosed regions *per se*, then both conditions should produce significant object-based effects similar to those reported by Egly et al. (1994). However, if attention is directed to objects *per se*, then the holes condition should not elicit these same effects as the regions will be perceptually grouped as part of one surface.

Method

Participants—Twenty-four UC Berkeley undergraduate students (age 18–28 years, $M = 21$ years) participated in the experiment, and received course credit for participation. All participants provided informed consent, reported right-handedness, normal or corrected-to-normal visual acuity and normal color vision.

Apparatus—The stimuli were presented on a 16″ Gateway 2000 Vivitron monitor. The monitor refresh rate was 100 Hz and the display was set to a 32bit mode at 800×600 pixel resolution. Three-dimensional viewing was attained through the use of CrystalEyes3 liquid crystal shutter eyeglasses and an E-2 emitter (Stereographics Corporation). Blue-line technology, which synchronizes the shutter glasses to the presentation of the stimuli, was used to present the stimuli with a lateral disparity of 12 pixels to each eye on alternating frames, creating the perception of depth. Participants sat at a viewing distance of 40 cm.

Stimuli—The stimulus displays occupied a visual angle of 24.81°. A white circle with a 24.81° diameter was presented as the background behind a pixelated 14.67° square surface. A pixelated surface was used because stereoscopic depth is most compelling when textures are present (Figure 2). A green 0.57° diameter circle with a 1 pixel black outline served as fixation. Two white rectangles were positioned symmetrically about the central fixation point and were both oriented either vertically or horizontally throughout each block. Each rectangle spanned 1.32° by 8.59°. The outer edges of the rectangles were 8.59° apart from one another. Targets were maximally-saturated pink (255, 0, 255) or blue (0, 0, 255) 0.29° squares. The cue was an outline of a 1.2° circle appearing within one end of a rectangle's boundaries. Targets were centered such that their position would correspond to the center of a cue presented at the same end of the same rectangle.

Orientation (horizontally- and vertically-oriented rectangles) and percept (objects and holes) were crossed to produce four stimulus conditions. Information from stereoscopic depth cues determined the perceptual organization of the displays. Horizontal displacement of either the

rectangles or the pixelated square surface determined whether the rectangles should be seen as objects in front of the pixelated surface or as holes in the pixelated surface, respectively. In the objects condition, the rectangles were seen in the front plane, with the background circle and pixelated surface in the plane of the screen. In this condition, the rectangular regions should be perceived as individuated objects. In the holes condition the pixelated surface (with two rectangular holes in it) was seen in the front plane, with the background circle in the plane of the screen (see Figure 2 for schematic depiction; note that the actual stimuli were not shaded). In this condition, the two rectangular regions should be perceived as part of the same homogeneous background surface (i.e., not as two objects)[2]. The fixation, cue, and target always appeared on one plane: either on the same plane as the rectangles (objects condition), or on the same plane as the background circular surface (holes condition).

Design—The location of the target, relative to the cue, determined the type of trial (Figure 1). The task in the present experiment was to discriminate the color of the target as rapidly as possible. Three fourths of the trials were *valid* trials, in which the target appeared in the same location as the cue (*valid* location). In the remaining trials, the target appeared equally often within the same rectangle but at the opposite end from where the cue appeared (*invalid-within*), or in the other rectangle but at the same end that the cue appeared (*invalid-between*). All trial types were randomly interleaved.

Procedure—Four (objects/horizontal, objects/vertical, holes/horizontal and holes/vertical) conditions were blocked and their order was counterbalanced across participants. Each block consisted of 32 practice trials and 128 experimental trials. The stereoscopic goggles made monitoring of eye movements impossible in this experiment, although central fixation was emphasized to the participants.

The participants were instructed to remain fixated on the green central fixation circle throughout each trial. At the beginning of each trial, an alerting tone sounded for 500 ms, followed by the presentation of the background circle, pixelated square, two rectangles and fixation circle alone for 1530 ms. This was then followed by the addition of a cue, which appeared for 140 ms. The cue disappeared, and a target followed 220 ms later for 1400 ms or until the participant made a response. A 500 ms ITI elapsed between trials (Figure 1). Participants were informed that the cue predicted the most likely location of the upcoming target and that they should respond as quickly and accurately as possible when the target appeared. To avoid possible contributions of stimulus/response spatial congruencies (i.e., the Simon effect--Simon, 1969), one response button was used. Participants were told to respond with either a single or double left mouse click, using their right index finger, to indicate whether the target was blue or pink. Half of the participants were instructed to respond to the pink target with one click and the blue target with two clicks, and half were instructed to respond in the opposite manner. RTs were measured from the first mouse click, while accuracy was recorded on the basis of one or two click responses.

Results

Errors were excluded from the RT analyses (each accounted for less than 1% of trials). Median RTs for were analyzed using repeated measures analysis of variance (ANOVA) techniques, and paired comparisons were run to investigate specific hypotheses. Alpha level was set at 0.05 for all statistical tests.

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[2]The participants were asked to describe the stimuli after each block. In 82% of the objects blocks and in 75% of the holes blocks, participants reported perceiving displays in the desired way.

Space-based Effects—To determine whether the cue was effective in orienting spatial attention we performed a 2 by 2 ANOVA with cue type (valid, invalid-within) and percept (holes, objects) as factors. RTs were significantly faster for valid than invalid-within conditions [$F(1,23) = 65.25$, $p < 0.001$]. Although this effect was numerically larger for the holes (37 ms) than the objects condition (33 ms), there was no significant interaction between cue type and percept [F<1] nor was there a main effect of percept [F<1]. Paired comparisons showed that the valid condition produced significantly faster RTs than the invalid-within for both objects [$t(23)= 5.44$, $p < 0.001$] and holes [$t(23)= 9.35$, $p < 0.001$]. Thus, spatial cuing effects were present whether the rectangles were perceived as holes or objects (Figure 3a).

Object-based Effects—Our primary objective was to determine if object-based effects differed when the rectangles were perceived as holes vs. objects. To address this question, we conducted a 2 by 2 ANOVA on cue type (invalid-within, invalid-between) and percept (holes, objects). There was no main effect of percept [F<1]. Responses for invalid-within conditions were faster than for invalid-between, producing a trend for a main effect of cue type [$F(1,23) = 3.05$, $p = 0.09$]. The interaction between cue type and percept was significant [($F(1,23) = 6.72$, $p = 0.02$]. Planned comparisons revealed that object-based effects were present for the objects condition [17 ms, $t(23)= 2.34$, $p < 0.03$], but not for the holes condition [1 ms, $t<1$] (Figure 3b). The magnitude of the object-based effect in the objects condition is consistent with many other studies using similar methods (Avrahami, 1999; Egly, Driver, & Rafal, 1994; Shomstein & Yantis, 2004).

Discussion

Experiment 1 revealed "space-based" effects in the holes and objects conditions: participants were faster to discriminate targets at validly- compared to invalidly-cued locations. More importantly, object-based effects (invalid-within vs. invalid-between) were found when the enclosed regions were perceived as individuated objects in front of a surface but not when the same regions were perceived as holes in that surface. These results are consistent with the hypothesis that enclosed regions alone are not sufficient for object-based attentional selection.

The lack of an object-based effect in the holes condition appears to be explained by object-based attention being allocated to the background circle and not by the enclosed regions *per se*. In other words, instead of being perceived as individuated objects, the enclosed regions grouped with the background which was a single homogeneous unit. This account is supported by evidence that object-based attention spreads across perceptually completed objects (Moore et al., 1998).

An alternative account for the current results is that some RT cost was associated with allocating attention to the depth plane furthest from the participant (holes condition), which negated any object-based effects between the invalid-within and invalid-between conditions. This possibility is raised by work showing that attentional allocation is sensitive to depth (see Atchley & Kramer, 2001; Atchley, Kramer, Andersen, & Theeuwes, 1997). In Experiment 2 we test this hypothesis by adding a condition in which attention is again allocated to the furthest depth plane, but now with the background is divided into two separate regions (i.e., background objects).

Experiment 2

In Experiment 2, the background circular surface was either connected (as in Experiment 1) or split into two separate semicircles. We again tested the hypothesis that enclosed rectangular regions were sufficient to elicit object-based effects and manipulated depth cues such that rectangles were perceived as either holes or objects. In addition, we tested whether object-based attention could be allocated to the background by separating it into two regions.

Methods

All methods are identical to those of Experiment 1 unless noted otherwise.

Participants—Sixteen new UC Berkeley undergraduate students aged 18–26 ($M = 21$ years) participated in the experiment.

Apparatus—The stimuli were presented on a 20″ ViewSconic G225fB monitor. The monitor refresh rate was 100 Hz and the display was set to 32 bit mode at 1280×960 pixel resolution.

Stimuli—The rectangles were always oriented horizontally in this experiment. The background circle from Experiment 1 was split[3] in half of the conditions in this experiment to examine whether the holes were grouping with the background object (Figure 4)[4]. Background (completed and split circle) and percept (objects and holes) were crossed to produce four stimulus conditions.

Design—The task in this experiment was the same as Experiment 1. Cues were valid on 75% of trials, with the remaining two conditions (invalid-within or invalid-between) each presented on 12.5% of trials.

Procedure—Four (foreground objects/completed circle, foreground objects/split circle, holes/completed circle and holes/split circle) conditions were blocked and their order was counterbalanced across participants.

Task, trial and response parameters were the same as in Experiment 1.

Results

Errors were excluded from the RT analyses (less than 1% of trials). Mean RTs were analyzed using repeated measures analysis of variance (ANOVA) techniques or planned comparisons, using a 0.05 alpha-level.

Space Based Effects—Space-based attention was analyzed by a $2 \times 2 \times 2$ ANOVA with cue type (valid, invalid-within), percept (holes, objects), and background (split, completed) as factors. RTs were significantly faster for valid than invalid-within conditions [$F(1,15) = 40.98$, $p < 0.001$]. Although this effect was numerically larger for the holes [37 ms, $t(15)= 6.19$, $p < 0.001$] than the objects condition [31 ms, $t(15)= 5.41$, $p < 0.001$], there was no significant interaction between cue type and percept [$F(1,15) = 2.03$, $p = 0.18$]. There were no main effects of background [$F(1,15) = 1.81$, $p = 0.20$] or percept [F<1]. The interaction between background (split, completed) and cue type was significant [$F(1,15) = 13.41$, $p < 0.01$]. Planned comparisons revealed significant space-based effects in both the split [29 ms, $t(15)= 5.50$, $p <0.001$] and completed background [39 ms, $t(15)= 6.87$, $p <0.001$] conditions. (Figure 5a). All other effects were non-significant [F<1].

Object-based Effects—To examine if object-based effects differed when the rectangles were perceived as holes vs. objects in the split and completed background conditions, we conducted a $2 \times 2 \times 2$ ANOVA on cue type (invalid-within, invalid-between), percept (holes, objects), and background (split, completed). Responses for invalid-within conditions ($M = 414$ ms) were faster than for invalid-between ($M = 425$ ms), producing a main effect of cue type [$F(1,15) = 10.22$, $p < 0.01$]. There was no main effect of background [$F(1,15) = 1.85$, $p = 0.20$]

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[3]A 1.71° rectangle was inserted in the middle of the circle to split the circle into two separate shapes, hereafter referred to as "semicircles".
[4]The participants were asked to describe the stimuli after each block. In 75% of the objects blocks, 81% of the completed background holes blocks, and 75 % of the split background holes blocks, participants reported perceiving displays in the desired way.

or interaction between background and cue type [$F(1,15) = 2.22$, $p = 0.16$]. All other effects were non-significant [$F<1$]. Planned comparisons revealed that object-based effects were present for the objects condition with the completed [12 ms, $t = 2.14$, $p = 0.05$] and split background [15 ms, $t = 2.12$, $p = 0.05$]. Most importantly, object-based effects were also present in the holes condition with the split background [14 ms, $t = 2.63$, $p = 0.02$], but not with the completed background [1 ms, $t<1$] (Figure 5b).

Discussion

As in Experiment 1, we found reliable space-based effects (valid vs. invalid-within) both when the rectangles were perceived as holes and objects. We replicated our findings from Experiment 1 when the background circle was completed: object-based effects were present when the enclosed regions were defined as foreground objects. As predicted by an object-based attention account, when the background was split to form two semicircles, object-based effects (invalid-within vs. invalid-between) reemerged in the holes condition. This result suggests that the rectangular regions in the holes condition grouped with the background surface, which itself was either one complete object or two separate objects.

In the completed background condition, boundaries of the holes did not slow RTs in the invalid-between condition, while in the split background condition, RTs were slowed even though the boundary itself was only implied. The boundaries of the two semicircles in the background were amodally completed and thus separated into two objects. These results compliment those of Moore et al. (1998) who showed that occlusion of an object did not affect within-object effects.

The RTs in the complete background condition for holes are also informative in evaluating whether the object-based effect reflects a cost to move attention between objects or a benefit to allocate attention within a selected object. For the completed holes condition, RTs were the same whether the target appeared within the cued hole or in the uncued hole, presumably because attention moved across the homogeneous space of the background. Note that these RTs were also more like the invalid-within condition than the invalid-between condition when the objects were in the foreground. When the target appeared on a different foreground object, RTs increased. These findings are consistent with a cost in moving attention from one object to another. One wonders why mean RTs in all the invalid-within conditions in the split background case were faster, although this difference did not reach significant levels. One possible explanation for the invalid-within difference is that in the completed background conditions, attention automatically spread across a larger surface area than in the split background conditions, where there were two smaller objects (Davis, Driver, Pavani, & Shepherd, 2000). Therefore, when the background was split, the invalid-within conditions required an attentional shift within a smaller object than in the completed background conditions. An alternate explanation for the faster invalid-within RTs in the split background conditions is that the gap between the two semicircles in the split background conditions added a line cue that was the same orientation as the rectangle, resulting in faster within-object RTs.

Importantly, Experiment 2 ruled out the possibility that the findings from Experiment 1 were based on depth *per se*. Namely, the presence and absence of object-based effects in enclosed regions was not modulated by whether the regions were perceived as lying in the closer or farther plane (relative to the participant). Instead, the object-based effects were modulated by whether the perceptual cues individuated regions, independent of whether perceived individuation occurred in the foreground or background.

General Discussion

The current investigation aimed to determine whether the presence of enclosed regions was sufficient to engage object-based attention, and found they are not. Previous studies have typically taken the opposite approach, addressing whether a perceptually degraded boundary (e.g., illusory contours, amodally completed region) is sufficient to engage object-based attention (Bertamini & Hulleman, 2006; Davis & Driver, 1997; Moore et al., 1998). Together these results demonstrate that the perceptual organization of regions as individuated objects is crucial in determining whether object-based selection will occur.

Perceptual Organization Influences Object-Based Attention

In both Experiments 1 and 2, participants were able to make use of the predictive cues: responses were faster when targets appeared in valid compared to invalid conditions. However, attentional allocation to invalid locations was different depending on the perceptual organization of the stimuli. In Experiment 1, when enclosed regions were perceived as part of a background surface (holes) the object-based effect was not present. However, object-based effects were reliable when the same enclosed regions were perceived as foreground objects. In Experiment 2, the object-based effect was again unreliable when the enclosed regions were perceived as a homogenous background surface, but only when the background was complete. When the background was perceived as two split semicircles (background objects), the object-based effect reemerged in the holes conditions. These results provide evidence that object-based attention is not selectively sensitive to an enclosed region *per se*, but requires something more. They strongly augment arguments for "object-based" selection by showing that the perceptual interpretation of an enclosed region in a stimulus as more or less object-like can modulate object-based effects dramatically, even when the physical properties of the enclosed regions are the same.

Differences Between Holes and Objects

In both experiments, the white enclosed regions perceptually grouped with the white circular background region in the holes condition, resulting in the representation of the rectangles as part of a background surface. This perceptual grouping caused the object-based effect in the holes condition to differ from the objects condition when the background was complete but not when it was split. Differences between holes and objects, due to perceptual organization, have been found by others as well (Hulleman & Humphreys, 2005; Nelson & Palmer, 2001). For instance, Bertamini and Croucher (2003) investigated how the shapes of holes are encoded using two regions which differed in the relative height of convexity or concavity vertices. The typical finding is that height judgments between convex vertices are faster than similar judgments between concave vertices (Bertamini, 2001). They also manipulated the figure/ground relationship of the stimuli to produce the perception of either a hole or an object. Because the bias in height judgments switched from convex to concave, they concluded that the shape of the boundary was assigned to the surrounding area, and not to the holes themselves. Hulleman and Humphreys (2005) further investigated the attentional differences between holes and objects using a search task in which participants had to search for a "C" among a group of "O" distracters. The letter stimuli were manipulated to produce the perception of either holes or objects. They found that participants were faster to identify the target as present in the objects conditions than in the holes conditions. They also found that this effect was strongly mediated by the letters grouping with the background region in the holes conditions.

Contours and Closure in Object-Based Attention

Closed areas that are defined by connected contours are normally perceived as objects, but some have questioned whether it is the objects per se, or the contours that define objects that are the most influential in object-based attention. For instance, Avrahami (1999) proposed that

the object-based effects were due to facilitation of attention to the cued rectangle in Egly et al. (1994) and the directional "grain" of the elongated lines between cues and targets. To support this claim, she showed that when a display of parallel lines was presented, targets appearing within a region (where a line did not have to be crossed) produced faster responses relative to those presented the same distance away from the cue but in a region where lines did have to be crossed. She concluded that object-based effects result from covert line tracing. However, in the current experiments, we demonstrated that even in the presence of a rectangle with contours that could be attentionally traced their designation as holes eliminated the object based effects. Object-based differences were instead modulated by whether the contours were perceptually organized as belonging to individuated rectangles (objects) or as part of an occluding surface (holes).

In a separate test of object-based selection based on a study by Lavie and Driver (1996), Crundall, Cole, and Galpin (2007) further tested whether lines direct attention. Participants were presented with two overlapping lines, and they were asked to judge whether two simultaneously presented targets were the same or different. Responses were analyzed in terms of whether the targets were part of the same line or part of different lines. Although within-line conditions produced faster responses, there were limits: if the line included a corner, within-line advantages disappeared. Their results converge with ours in demonstrating that lines are not always sufficient for guiding attention, just as enclosed regions are not always sufficient. Rather it is the perceptual organization of a stimulus that guides both space-based and object-based attention (see also Robertson & Kim, 1999).

Similar work by Marino and Scholl (2005), examining the effects of closure on "objecthood" also provides evidence that line tracing cannot provide a sufficient account for object-based effects. They found that object-based effects were increased when the rectangles were enclosed compared to when they were not, and concluded that "objecthood" is modulated by many different perceptual cues. Their conclusion that object-based attention hinges on multiple perceptual cues interacting, in a possibly hierarchical structure, is consistent with the current results (see also Ben-Shahar, Scholl, & Zucker, 2007).

Conclusions

In general, the results from the present experiments highlight the importance of perceptual organization in the allocation of visual attention. Importantly, we showed that enclosed regions are *not* sufficient for object-based selection to occur. By splitting the background region, we also ruled out the possibility that an effect of attention in depth caused the lack of an object-based effect in the holes condition in Experiment 1. We found instead that object-based attention was oriented to the background surface when the rectangles grouped with the background (holes). Based on these findings, we suggest that when the background was perceived as unitary and the rectangles as holes, object-based attention was not observed because attention was allocated to the background "object". When the background was split in two, the object-based effect reemerged. In other words, in the holes conditions, when the background is completed there is only one surface over which object-based attention is allocated. When the background is split, two surfaces emerge, reinstating the object-based effect. Our results demonstrate that enclosed regions are not sufficient to indiscriminately engage object-based attention. In conjunction with previous studies showing that degraded objects can elicit object-based selection, the present investigation further highlights the importance of perceptual organization in the allocation of visual attention.

Acknowledgements

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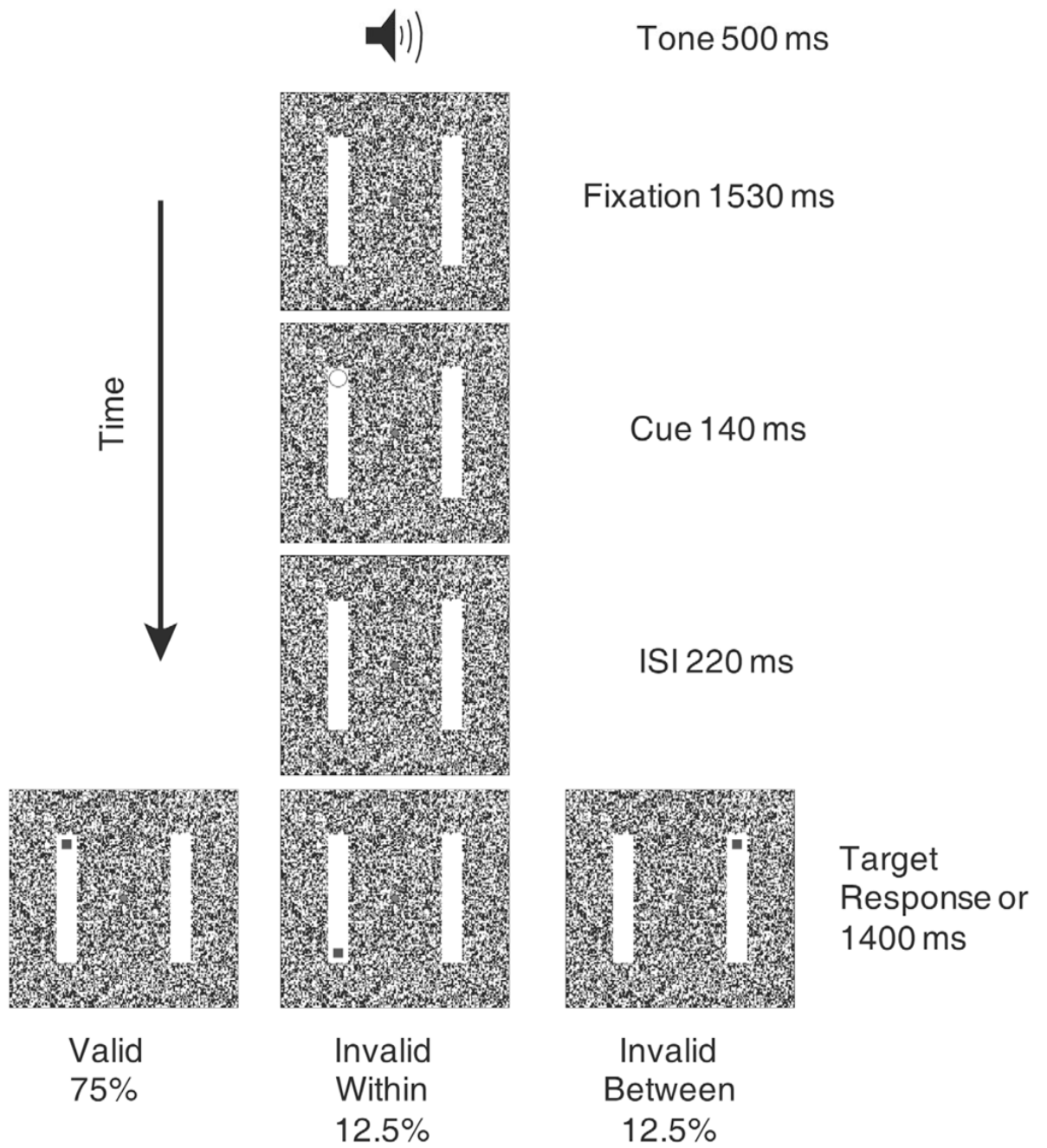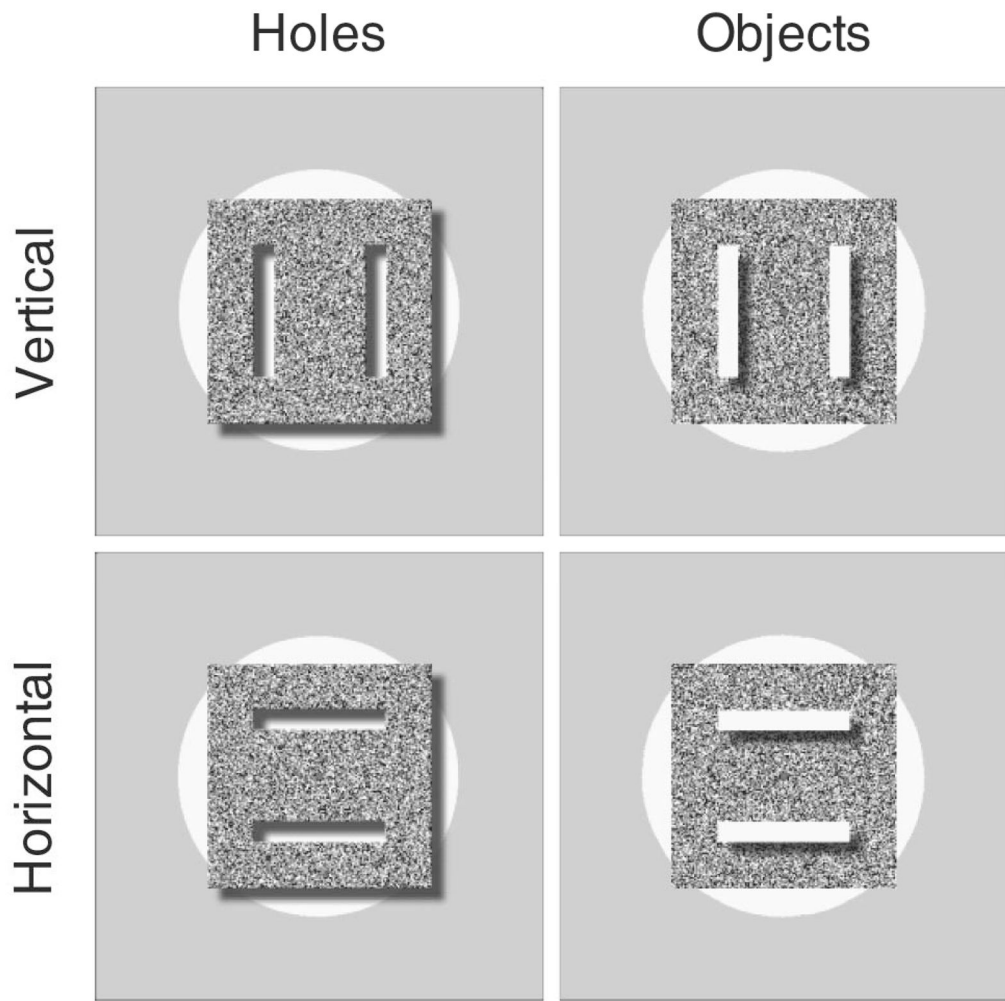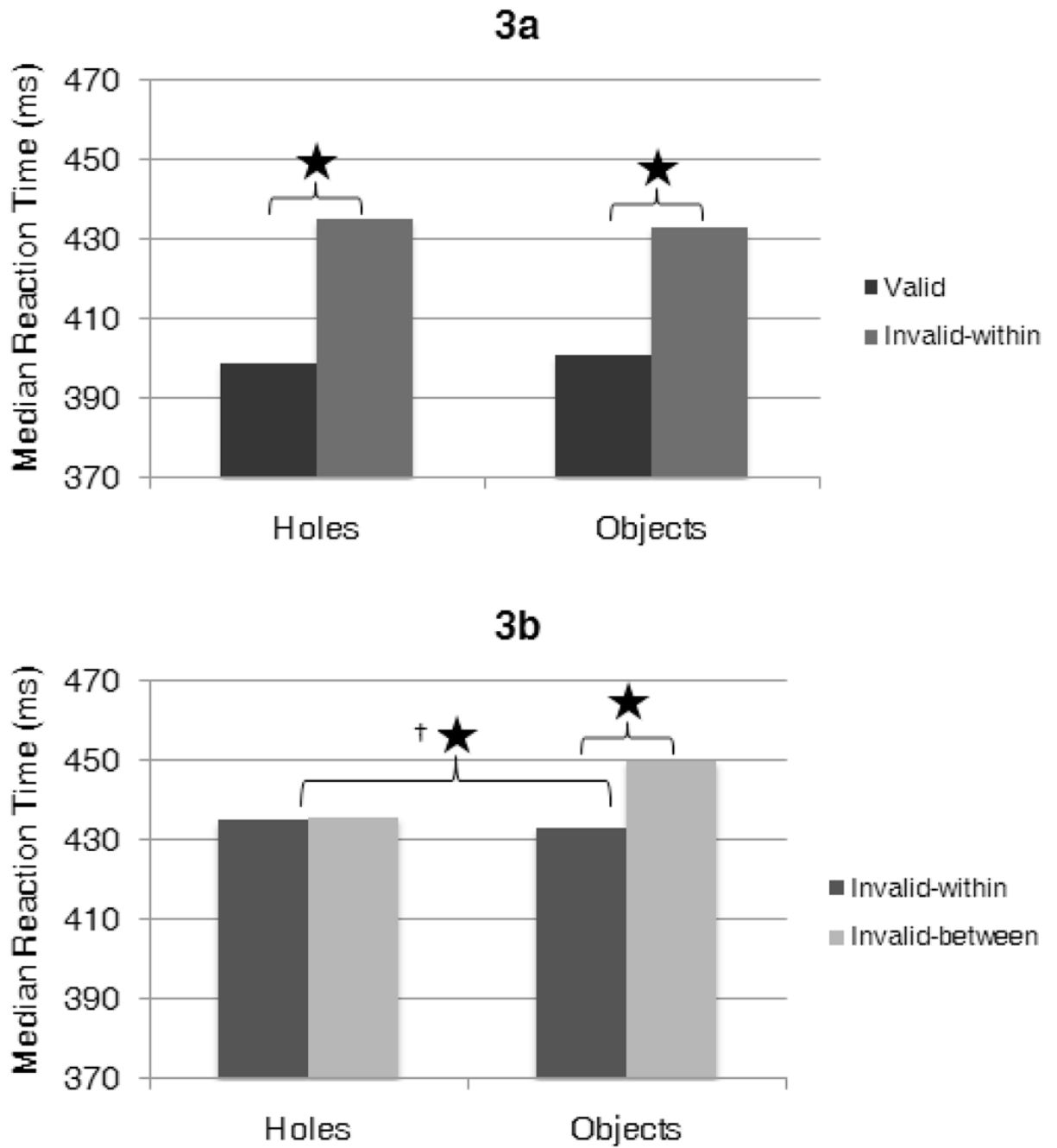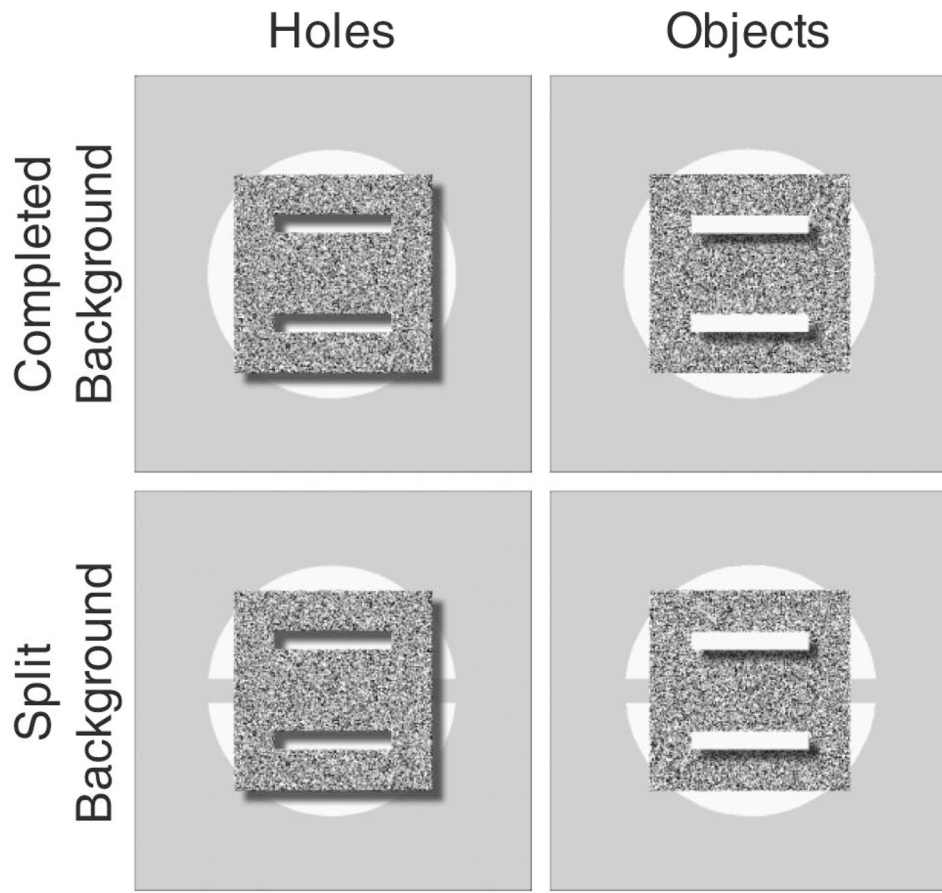
Figure 1.

Figure 2.

Figure 3.

Figure 4.

5a

5b

Figure 5.