Research Article

Central-Cue Discriminability Modulates Object-Based Attention by Influencing Spatial Attention

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Abstract. The role of central-cue discriminability in modulating object-based effects was examined using Egly, Driver, and Rafal's (1994) "double-rectangle" spatial cueing paradigm. Based on the *attentional focusing hypothesis* (Goldsmith & Yeari, 2003), we hypothesized that highly discriminable central-arrow cues would be processed with attention spread across the two rectangles (potential target locations), thereby strengthening the perceptual representation of these objects so that they influence the subsequent endogenous deployment of attention, yielding object-based effects. By contrast, less discriminable central-arrow cues should induce a more narrow attentional focus to the center of the display, thereby weakening the rectangle object representations so that they no longer influence the subsequent attentional deployment. Central-arrow-cue discriminability was manipulated by size and luminance contrast. The results supported the predictions, reinforcing the attentional focusing hypothesis and highlighting the need to consider central-cue discriminability when designing experiments and in comparing experimental results.

Keywords: object-based attention, visual attention, spatial cueing, perceptual organization

A great deal of research has examined whether visual attention is directed to unparsed regions of space (i.e., space-based attention) or to perceptual objects formed by preattentive segmentation and grouping processes (i.e., object-based attention; see, e.g., Egeth & Yantis, 1997; Goldsmith, 1998; Scholl, 2001). In support of the space-based view, detection and identification responses are generally faster and more accurate for targets presented at spatially cued locations than at other locations, with the differences increasing as the cue-target distance is increased (e.g., Eriksen & St. James, 1986). Other work, however, supports the object-based view. For example, in a highly influential adaptation of the spatial cueing paradigm, in which each of four potential target locations is encompassed by one of two different rectangle objects, Egly, Driver, and Rafal (1994) found that detection of targets on invalid-cue trials was faster when the uncued and cued locations were at opposite corners of the same rectangle object than when they were at equally distant corners of two different objects. This object-based effect (same-object advantage) was in addition to a space-based effect (same-location advantage), by which detection at the cued location was faster than detection at the uncued location within the same object.

Subsequent studies, using various adaptations of the Egly et al. (1994) paradigm, have revealed that object-based effects are not observed under all conditions (for reviews, see Goldsmith & Yeari, 2003; Mozer & Vecera, 2005). Of particular relevance to the present article, some findings have suggested that object-based attention might be modulated by the mode of attentional control, endogenous versus exogenous. Macquistan (1997), for example, observed a same-object advantage using exogenous, peripheral cueing, by which attention is captured automatically, but not using endogenous, central-arrow cueing, by which attention is directed voluntarily to the target location (for similar results, see Dagenbach, Goolsby, Neely, & Dudziak, 1997; Neely & Dagenbach, 1996). This pattern was taken to imply a possible interdependence between mode of control (exogenous vs. endogenous) and mode of selection (object-based vs. space-based).

However, pointing to a potential confound between the type of cue and the spatial distribution of attention (focused or spread) while processing the cue, Goldsmith and Yeari (2003) put forward a different explanation of the general pattern, in terms of an *attentional focusing hypothesis*: Under peripheral-exogenous cueing, participants presumably spread their attention broadly over both rectangle objects while waiting for the (uninformative) cue and target to appear. Being encompassed within the focus of attention, these objects should have viable perceptual representations that are capable of influencing the subsequent deployment of attention to the cued location. By contrast, under endogenous-central cueing, participants are likely to focus their attention more narrowly on the central display region while preparing for and processing the direction of the arrow cue. This could create a state of *inattention* (Mack & Rock, 1998) with respect to the rectangle objects, degrading their perceptual-object representations to the point that they no longer affect the subsequent allocation of attention.

To examine this idea, Goldsmith and Yeari (2003) conducted a series of experiments in which type of cueing and initial spatial focus of attention were orthogonally manipulated. The results indicated that initial spatial focus – not type of cueing – was the critical factor modulating object-based effects: Object-based effects were observed under endogenous cueing when auditory cues allowed participants to maintain an initially diffuse attentional setting (Experiment 2), when central-arrow cues were accompanied by explicit instructions to spread attention while waiting for and processing the cue (Experiment 3), and when peripheral-cue and central-arrow-cue trials were randomly intermixed in the same block, so that the most expedient strategy would be to adopt a common, spatially diffuse attentional setting for all trials (Experiment 4). Conversely, object-based effects were attenuated under exogenous cueing when the task required participants to focus their attention narrowly on a small, centrally presented "go/no-go" cue prior to the onset of the exogenous peripheral cue (Experiment 5). Beyond refuting the suggested interdependency between mode of spatial cueing and mode of attentional selection, these findings bring to the fore the crucial role of the initial spatial distribution of attention in determining the representation and organization of perceptual objects (e.g., Kimchi & Razpurker-Apfeld, 2004; Mack & Rock, 1998), thereby modulating object-based effects (cf. Lavie & Driver, 1996).

Having established the role of (prior) spatial focus in modulating (subsequent) object-based attention, there is still a need to address some apparent anomalies in the literature. For example, contrary to the general pattern described earlier, Abrams and Law (2000) reported a series of experiments in which object-based effects were observed using endogenous central-arrow cues. In discussing those results, Goldsmith and Yeari (2003) suggested several factors that might induce the formation of robust perceptual-object representations despite initially focused attention, such as the use of objects that are highly salient and well formed or that are configurally related to the targets. They also pointed to conditions that might lead participants to adopt a relatively diffuse attentional setting despite the need to process the central-arrow cue: for example, tasks that require the comparison of spatially distributed targets (e.g., same-different), or highly discriminable central-arrow cues that can be utilized easily and effectively without focused attention.

In the present study we addressed this latter idea, examining whether cue discriminability might in fact play a role in modulating object-based effects under central-endogenous cueing. Using the double-rectangle spatial cueing paradigm, we manipulated the discriminability of the central arrow cue by varying its size and luminance contrast, such that the high-discriminability cue was both longer and darker than the low-discriminability cue. The cues were highly predictive of target location (80% validity). We hypothesized that in order to process the low-discriminability cue, participants would initially focus their attention narrowly at the center of the display, thereby weakening the perceptual representation of the rectangle objects and preventing them from influencing the subsequent endogenous deployment of attention (no object-based effect). In contrast, because the direction of the high-discriminability cue should be easily discernable under spread attention, we expected that the participants would adopt such a strategy, thereby strengthening the perceptual representation of these objects so that they guide the subsequent attentional deployment, thereby yielding object-based effects.

Note that for both levels of cue discriminability, we expected that a cue-target SOA of 300 ms would be sufficient to interpret the cue and orient attention to the cued location before target onset. Thus, we did *not* expect any difference in the magnitude of the cue-validity effect or in overall RT between the two cue-discriminability conditions. In analyzing the results, we focused on the interaction effect involving cue discriminability in two planned orthogonal contrasts: one reflecting the effect of cue validity (validly vs. invalidly cued targets) and the other reflecting the same-object advantage on invalid-cue trials (invalid same-object targets vs. invalid different-object targets). The interaction effect in the latter contrast directly examines the main hypothesis, that object-based effects depend on cue discriminability, whereas the former contrast is needed to verify that differences in the same-object advantage between the cue-discriminability conditions do not stem from differences in the effectiveness of the orienting cues.

Method

Participants

Twenty undergraduate students at the University of Haifa participated in the experiment for payment. All participants had normal or corrected-to-normal vision.

Apparatus and Stimuli

The experiments were run using an IBM PC compatible computer and a Super VGA, high-resolution color monitor. Participants viewed the monitor from a distance of 80 cm with their heads resting on a chin rest in a dimly lit room.

The stimuli were gray (RGB values: 100, 100, 100) on a white background (see Figure 1). The fixation cross subtended $0.6° \times 0.6°$. The two parallel rectangles, drawn with a line width of 0.15°, were oriented either horizontally or vertically, each subtending $10° \times 2°$, with midpoints 3.9° to either side of the fixation point. The target was an equilateral triangle, subtending 1° along the base and 0.8° in height. It was always presented at the end of one of the rectangles, 5.8° from the fixation point, with one of its vertices oriented either up or down. *Cue discriminability* was manipulated by two different arrow cues: The high-discriminability cue was a straight line segment subtending 2.3° in length and 0.4° in width. The low-discriminability cue was a shorter line segment, subtending 0.6° in length and 0.4° in

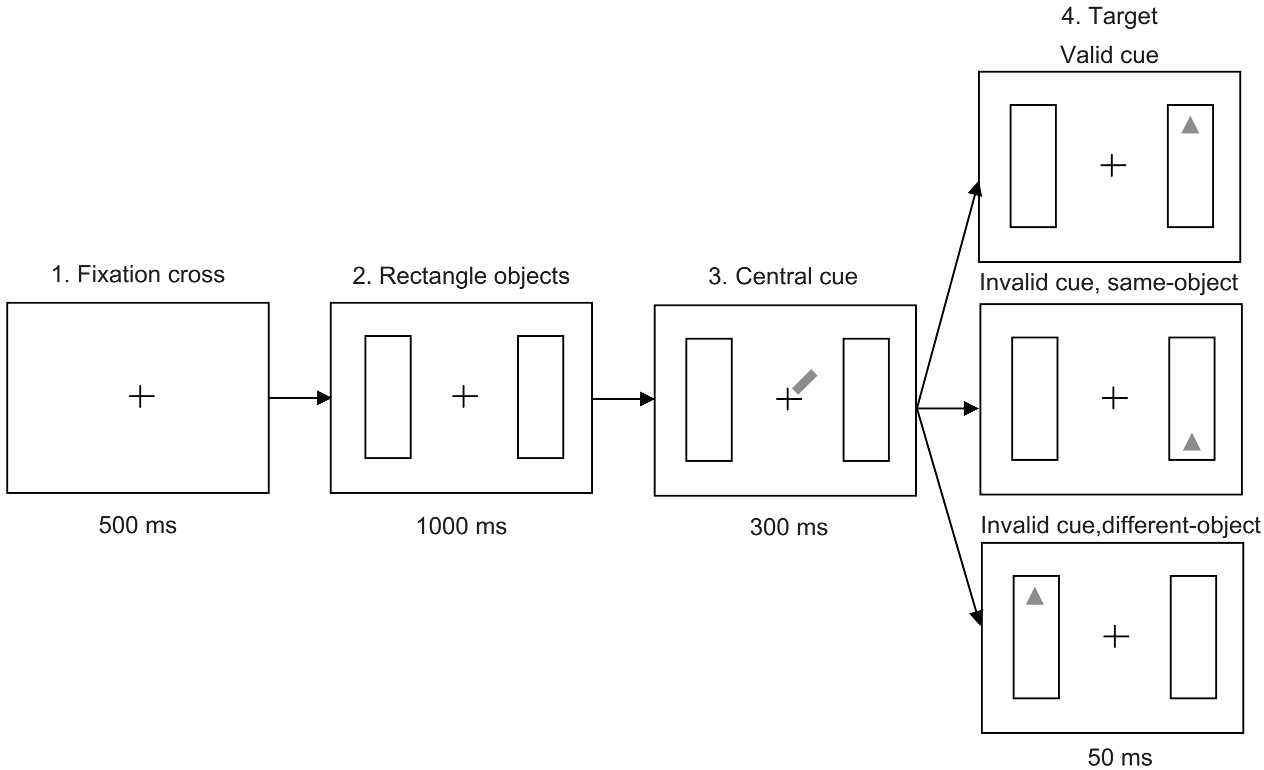

Figure 1. Sequence of events in an experimental trial including exposure durations. Rectangle objects remained on screen until response.

width, of lower luminance contrast (RGB values: 150, 150, 150).[1] Both types of cues were displayed with one end 0.5° from the central fixation point, oriented at either 45°, 135°, 225°, or 315° from vertical (i.e., pointing to one of the four possible target locations).

Procedure

Participants were run individually. They received a verbal description of their task, and any questions were answered. The importance of maintaining eye fixation throughout each trial was stressed. They were given a block of practice trials that were similar to the experimental trials, during which the experimenter was seated where he could observe the participants' eyes. The practice block continued until the participant had completed 20 consecutive practice trials without eye movements. The cue-discriminability manipulation was performed within participants in two separate sessions in counterbalanced order, separated by about 1 week. Cue discriminability was blocked to enable participants to adopt different focusing strategies for each type of cue (cf. Goldsmith & Yeari, 2003, Experiment 4, in which intermixed central-cue and peripheral-cue trials induced a common, spread attention strategy for all trials). Each 45-min session consisted of one practice block, followed by four blocks of 1,200 trials.

Each trial began with a blank screen for 0.5 s, and then the fixation cross appeared at the center of the screen (see Figure 1). After 0.5 s the rectangles appeared, oriented horizontally or vertically with equal probability and remaining on the screen throughout the trial. One second after the rectangles appeared, the central-arrow cue was presented for 300 ms, pointing to one of the four possible target locations. Immediately upon cue offset, the target triangle was presented for 50 ms at one of the four potential target locations. The target pointed up or down with equal frequency and appeared with equal frequency at either end of either rectangle. The participants' task was to indicate, by a key press, the orientation of the target triangle (up or down). Participants were instructed to respond as quickly as possible without making errors.

The central cue was highly predictive of the target's subsequent location: 80% of the trials were valid-cue trials, and the remaining trials were divided equally between two

[1] One might be concerned that perhaps object-based effects are modulated by the luminance contrast per se, with matched contrast between the central cue and the rectangles yielding object-based effects and mismatched contrast attenuating such effects. However, in direct opposition to the results reported here, previous studies have demonstrated the absence of object-based effects with matched luminance contrast (e.g., Goldsmith & Yeari, 2003; Macquistan, 1997) and the presence of object-based effects with mismatched luminance contrast (e.g., Chen & Cave, 2008).

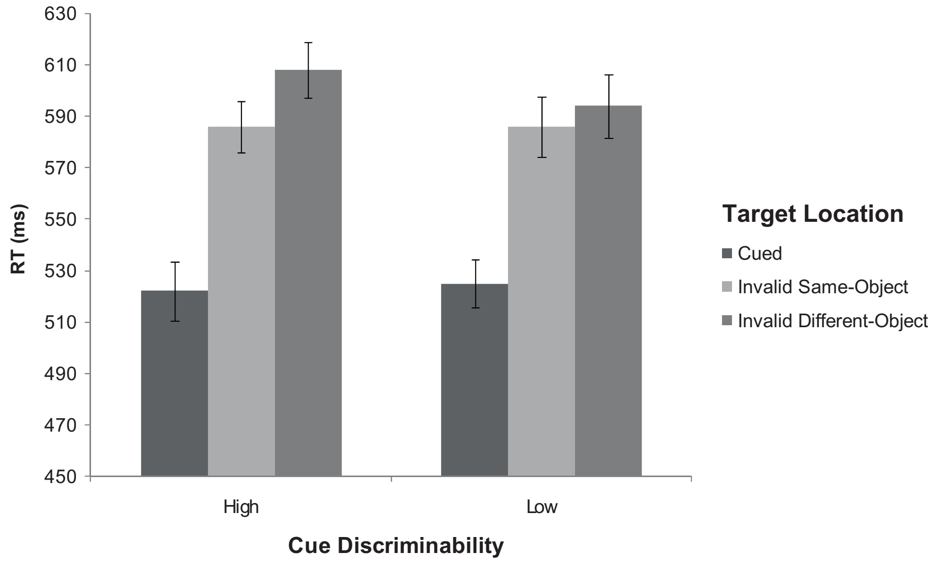

Figure 2. Mean response latency (RT) as a function of cue discriminability and target location. Error bars represent within-participant 95% confidence intervals (see Morey, 2008).

invalid-cue conditions: same-object trials (the target appeared at the far end of the cued rectangle), equidistant different-object trials (the target appeared at the near end of the opposite rectangle).[2]

Results

Mean correct response latencies (RT) and error rates were calculated for each participant separately for the high- and low-discriminability cue conditions in each of the three relevant target locations: cued targets, invalidly cued same-object targets, and (equidistant) invalidly cued different-object targets. The RT means were trimmed by omitting outlier trials falling more than ±2.5 *SD* from the mean of that particular cell (2.6% of the trials). The trimmed RT means are displayed in Figure 2. The mean error rates are presented in the text.

A two-way repeated-measures analysis of variance (ANOVA), Cue Discriminability × Target Location, was performed on the latency data, using planned orthogonal contrasts to examine cue-validity and object-based effects (see Introduction). First, comparison of RT for validly versus invalidly cued targets yielded a significant validity effect, with validly cued targets (523 ms) discriminated faster than targets appearing in one of the two invalid-cue locations (593 ms), $F(1, 19) = 71.8$, $MSE = 1362$, $p < .001$, $\eta_p^2 = .79$. Importantly, as expected, there was no interaction with cue discriminability, $F(1, 19) = 1.2$, $MSE = 434$, $\eta_p^2 = .06$, indicating that despite its smaller size and lower luminance contrast, the low-discriminability cue was as effective as the high-discriminability cue in orienting attention to the cued location.

Object-based effects were examined on invalid-cue trials by comparing RT to targets appearing in the same-object and different-object locations. Across the two cue-discriminability conditions, a same-object advantage was observed, $F(1, 19) = 5.9$, $MSE = 783$, $p < .05$, $\eta_p^2 = .24$. Importantly, however, this advantage was qualified by the predicted interaction between cue discriminability and target location,[3] $F(1, 19) = 3.8$, $MSE = 274$, $p < .05$, $\eta_p^2 = .16$: Whereas in the low-discriminability cue condition, there was a nonsignificant 8 ms difference in RT between targets appearing at the same-object (586 ms) and different-object (594 ms) locations, $F(1, 19) = 0.8$, $MSE = 745$, $\eta_p^2 = .04$, in the high-discriminability cue condition, a significant 22 ms same-object advantage was observed, with same-object targets (586 ms) responded to faster than the equally distant different-object targets (608 ms), $F(1, 19) = 16.0$, $MSE = 312$, $p < .001$, $\eta_p^2 = .46$.

To verify that the observed pattern of latency results was not due to a speed-accuracy tradeoff, a similar analysis was conducted on the error rates. The mean error rates of the valid, invalidly cued same-object, and invalidly cued different-object conditions, respectively, were 1.9%, 2.3%,

[2] Note that in conformity with the standard design in the double-rectangle task (Egly et al., 1994), the vast majority (90%) of the targets appeared within the cued object, which could in itself induce an attentional bias toward cued-object locations (see Shomstein & Behrmann, 2008, p. 133, for discussion). Importantly, however, to the extent that such a bias exists, it should be equally strong in both cue-discriminability conditions and therefore could not account for the predicted interaction in this study.

[3] Because the predicted interaction was directional (same-object advantage in the high-discriminability cue condition but not in the low-discriminability condition), its statistical significance was examined by a one-tailed paired *t*-test comparing the size of the same-object advantage between the two conditions (one-tailed $p = .033$; two-tailed $p = .066$).

and 2.8% for the high-discriminability cue condition and 2.2%, 2.9%, and 3.5% for the low-discriminability cue condition. Neither the validity effects for the high-discriminability, $F(1, 19) = 2.2$, $MSE = 1.6$, $\eta_p^2 = .10$ and low-discriminability, $F(1, 19) = 2.3$, $MSE = 4.5$, $\eta_p^2 = .10$ cue conditions, nor the object-based effects for the high-discriminability, $F(1, 19) = 0.3$, $MSE = 2.7$, $\eta_p^2 = .05$ and low-discriminability, $F(1, 19) = 0.8$, $MSE = 5.0$, $\eta_p^2 = .04$, cue conditions, were significant; all were numerically consistent with the latency results. Thus, a speed-accuracy tradeoff is not a concern.

Discussion

The results of this study confirm that central-cue discriminability does in fact modulate object-based attention: Whereas with the highly discriminable arrow cue, responses were faster for targets appearing at the uncued end of the cued rectangle object compared to targets appearing at an equally distant location in a different object, with the less discriminable cue no such same-object advantage was observed.[4] Importantly, this difference did not stem from differences in the ease or effectiveness of utilizing the cues to orient attention, as cue-validity effects were equivalent in the two conditions.

The manner in which central-cue discriminability modulates object-based attention is explained by the attentional focusing hypothesis (Goldsmith & Yeari, 2003) in terms of differences in the way the two types of cues are themselves attended to: Central-arrow cues that are sufficiently discriminable can be processed with attention spread across the two rectangles (the potential target locations), reinforcing the perceptual representation of these objects so that they influence the subsequent endogenous deployment of attention. By contrast, less discriminable central-arrow cues may induce or require a more narrow attentional focus to the center of the display, thereby weakening the rectangle object representations to such an extent that they no longer influence the subsequent attentional deployment.

The present finding, with its explanation in terms of the attentional focusing hypothesis, has both methodological and theoretical implications. First, at the methodological level, it points to the size and overall discriminability of the central-arrow cue as an important variable to consider, along with other variables that may affect the spatial distribution of attention, both in designing experiments and in comparing results between different studies. In this regard, it is worth noting that in attempting to reconcile the presence of object-based effects under central cueing in their study with the absence of such effects in prior studies, Abrams and Law (2000) examined several potential factors, none of which appeared to account for the inconsistent results. Unfortunately, lack of detailed information regarding the size, shape, and luminance contrast of the arrow cue used in their study precludes a consideration of the possible role of this factor in accounting for their results.

Second, at a more general theoretical level, the results of this study bring to the fore the potentially complex temporal and spatial dynamics of attentional focusing and orienting during the course of an experimental trial (visual scan; see also Yeari & Goldsmith, 2011). In particular, they highlight how prior attentional focusing influences and constrains subsequent attentional orienting by determining the perceptual organization and quality of the object representations that exist at each point in time.

Of course, both the spatial spread or focus of attention and the perceptual organization and representation of objects are presumably influenced by top-down, strategic factors as well as bottom-up stimulus variables (e.g., Shomstein & Behrmann, 2008; Watson & Kramer, 1999; Yeari & Goldsmith, 2010). Thus, for example, Goldsmith and Yeari (2003), after failing to find object-based effects using a central-arrow cue of intermediate size (1.2° × 0.4°; see also Macquistan, 1997), found that simply instructing the participants to avoid focusing their attention on the central cue (Experiment 4) was sufficient to reinstate the object-based effects. The same was true, without any special instructions, on central-arrow trials that were randomly intermixed with peripheral-cue trials, thereby making it strategically expedient to adopt a spread attentional setting for all trials (Goldsmith & Yeari, 2003, Experiment 5). In a similar vein, Chen and Cave (2008) found object-based effects using central-arrow cues of similar size to the Macquistan (1997) and Goldsmith and Yeari (2003) studies, in a task involving "same-different" judgments to two targets appearing simultaneously in different display locations. As they noted, in order to perform the task, "participants had to adopt an attentional focus that was broad enough to include both targets" Chen and Cave (2008, p. 1436).

In sum, the manner in which attention is allocated, and in particular, whether that allocation will be purely space based or instead influenced by perceptual objects, appears to depend on stimulus-related, task-related, and top-down strategic variables, such as the type of task (e.g., discrimination vs. detection or same-different judgments; Chen & Cave, 2008; Vecera & Farah, 1994), spatial uncertainty (Alvarez & Scholl, 2005; Shomstein & Yantis, 2002), object salience (Goldsmith, Yeari, Fyodorov, & Friedman, 2006; Shomstein & Behrmann, 2008), object exposure duration (Chen & Cave, 2008; Law & Abrams, 2002; Shomstein & Behrmann, 2008), uniform connectedness (Goldsmith et al., 2006; Watson & Kramer, 1999), subjective object interpretation (Chen, 1998; Chen & Cave, 2006; Watson & Kramer, 1999), and strategic expedience (Shomstein & Behrmann, 2008; Yeari & Goldsmith, 2010). The influence of some or all of these variables may perhaps be mediated by differences in the spread or focus of attention, leading to differences in the perceptual organization and quality of the stimulus objects. The present study adds one more variable to be considered in this complex equation – the perceptual discriminability of the central-endogenous cue, as it influences the initial spatial distribution of attention.

[4] Actually, inspection of Figure 2 suggests that the object-based effect in the high-discriminability cue condition may constitute a different-object cost rather than a same-object advantage (cf. Brown & Denny, 2007).

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