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Modulation of Object-Based Attention by Spatial Focus Under Endogenous and Exogenous Orienting

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In R. Egly, J. Driver, and R. D. Rafal's (1994) influential double-rectangle spatial-cuing paradigm, exogenous cues consistently induce object-based attention, whereas endogenous cues generally induce space-based attention. This difference suggests an interdependency between mode of orienting (endogenous vs. exogenous) and mode of selection (object based vs. space based). However, mode of orienting is generally confounded with initial focus of attention: Endogenous orienting begins with attention focused on a central cue, whereas exogenous orienting begins with attention widely spread. In this study, an attentional-focusing hypothesis is examined and supported by experiments showing that for both endogenous and exogenous cuing, object-based effects are obtained under conditions that encourage spread attention, but they are attenuated under conditions that encourage focused attention. General implications for object-based attention are discussed.

A central issue in research on visual attention concerns the nature of attentional representation and processing, in particular whether attention is allocated to unparsed regions of space or to perceptual objects (see, e.g., Egeth & Yantis, 1997; Goldsmith, 1998; Scholl, 2001). On the one hand, a great deal of work has indicated that attention is allocated to regions of space, with the efficiency of this allocation modulated by spatial parameters. For example, the amount of interference from distractor stimuli in selective-filtering tasks tends to decrease as the distractor–target distance is increased (e.g., C. W. Eriksen & Hoffman, 1972), whereas the cost of dividing attention between two stimuli tends to increase as the distance between them increases (e.g., Hoffman & Nelson, 1981; but see Bahcall & Kowler, 1999). Much of the evidence for the space-based view comes from spatial-cuing experiments (e.g., C. W. Eriksen & Hoffman, 1974; C. W. Eriksen & St. James, 1986; Posner, 1980; Posner, Snyder, & Davidson, 1980). In the standard paradigm, participants are cued to attend to a peripheral location in the visual field without making eye movements. Detection and identification responses are generally faster and more accurate for targets presented at cued locations than for targets at uncued locations, with the differences increasing as the cue–target distance is increased.

On the other hand, many studies support the view that attention is allocated to perceptual objects (e.g., Duncan, 1984; Kahneman & Treisman, 1984), defined by uniform connectedness (Palmer & Rock, 1994) or Gestalt grouping principles (Wertheimer, 1923). For example, all else (e.g., spatial separation) being equal, the amount of interference from distractor stimuli in selective-attention tasks is greater when the target and distractors are more strongly grouped (e.g., Baylis & Driver, 1992; Driver & Baylis, 1989; Kramer & Jacobson, 1991; Pomerantz, 1981) or are perceived as constituting a single object (e.g., Pomerantz & Pristach, 1989; Treisman, Kahneman, & Burkell, 1983), and dividing one's attention between two stimuli that are strongly grouped or between features that pertain to the same object is more efficient than dividing attention between weakly grouped stimuli or features of different objects (e.g., Baylis, 1994; Baylis & Driver, 1993; Behrmann, Zemel, & Mozer, 1998; Chen, 2000; Duncan, 1984; Goldsmith, 1998; Pomerantz, 1981; Pomerantz & Pristach, 1989; Treisman et al., 1983; Vecera & Farah, 1994; Watson & Kramer, 1999).

Of particular relevance to the present article, object-based effects have also been found in the spatial-cuing paradigm. In a clever and influential adaptation of this paradigm, Egly, Driver, and Rafal (1994) presented participants on each trial with two parallel rectangles, oriented either vertically or horizontally. The task was to detect a small target square that filled in one end of one of the rectangles. Shortly before target onset, the end of one of the rectangles was brightened briefly as a cue. On 75% of the trials (valid-cue trials), the target in fact appeared in the cued location. On the remaining (invalid-cue) trials, the target was presented at one of two locations that were equally distant from the cued location: (a) at the far end of the same rectangle (same-object target) or (b) at the near end of the other rectangle (different-object target). Egly, Driver, and Rafal (1994) found that overall, detection was faster for validly cued targets than for invalidly cued targets (including same-object targets), indicating that location or distance from the cue was affecting performance—a space-based effect. In addition, when invalid-cue trials were examined separately, detection was faster for same-object targets than for different-object targets, despite their equivalent distance from the cued location, indicating that the encompassing rectangle was also influencing

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the allocation of attention—an object-based effect. Similar results have been obtained in many subsequent studies using various adaptations of the paradigm (e.g., Atchley & Kramer, 2001; Behrmann et al., 1998; Lamy & Egeth, 2002; Moore, Yantis, & Vaughan, 1998).

The finding of both space-based and object-based effects in the Egly, Driver, and Rafal (1994) study, among others (see also Vecera, 1994; Vecera & Farah, 1994), has had considerable impact on the debate concerning object-based versus space-based attention.[1] The growing consensus is that attentional selection may have both space-based and object-based components, leading researchers to examine the nature of the coexistence and possible interactions between the different modes of attentional selection and processing (e.g., Arrington, Carr, Mayer, & Rao, 2000; Atchley & Kramer, 2001; Driver, Davis, Russell, Turatto, & Freeman, 2001; Goldsmith, 1998; Grossberg, Mingolla, & Ross, 1994; Humphreys, Olson, Romani, & Riddoch, 1996; Humphreys & Riddoch, 1993; Lavie & Driver, 1996; Logan, 1996; Robertson & Kim, 1999).

One outgrowth of this general change in approach has been the search for the boundary conditions or moderators of object-based attention. That is, instead of asking whether attention is object based or space based, the question becomes this: When (i.e., under what conditions) is attention object based, and when is it space based? The identification of the variables that constrain and modulate object-based attention can provide insight into the division of labor between the object-based and space-based modes of attention and the manner in which they interact.

Several potential moderator variables of object-based attention have been proposed and examined (see the General Discussion). One proposal, which motivated the present research, concerns the mode of attentional cuing—endogenous versus exogenous (e.g., Macquistan, 1997). In general, the findings from the double-rectangle cuing task suggest that exogenous (peripheral) precues, which capture attention automatically, induce object-based selection (i.e., a same-object advantage on invalid-cue trials), whereas endogenous (central) cues, which are used to guide attention voluntarily, induce space-based selection (i.e., no same-object advantage; see Arrington, Dagenbach, McCartan, & Carr, 2000; Dagenbach, Goolsby, Neely, & Dudziak, 1997; Macquistan, 1997; Neely & Dagenbach, 1996). Such a generalization, were it to hold, would have important implications not only for the understanding of object-based and space-based attention but also concerning the proposed differences between the endogenous and exogenous modes of attentional orienting (Posner, 1980; for reviews of the latter topic, see Kinchla, 1992; Yantis, 2000). In particular, the specific absence of endogenous object-based attention (i.e., object-based attention in response to endogenous spatial cues) would imply that the space–object and endogenous–exogenous dimensions of visual attention are interdependent, calling for an integrative theoretical framework (cf. Lauwereyns, 1998).

In one notable exception to the pattern just described, Abrams and Law (2000) reported a series of experiments in which object-based effects were observed with endogenous as well as exogenous cues, raising doubts about the simplicity of the relationship (a detailed discussion of their results is deferred to the General Discussion). Nevertheless, there is still an intriguing consistency in the inconsistency: Peripheral–exogenous cues yield consistent evidence of object-based selection, whereas central–endogenous cues yield inconsistent results, with a clear trend toward space-based selection. What might account for this difference?

In this article, we put forward the hypothesis that the critical variable modulating object-based attention in spatial cuing tasks and in other tasks involving dynamic attentional orienting is not the type of cuing or the ensuing mode of orienting but, rather, the spatial distribution of attention just prior to its deployment. We now turn to an explication of the hypothesis, and then we report a series of experiments supporting it.

How Attentional Focusing Might Modulate Object-Based Attention in the Double-Rectangle Cuing Task

Macquistan (1997) adapted the double-rectangle cuing task to examine the relationship between mode of attentional cuing and object-based attention (see Figure 1). He pointed out that the peripheral cue used by Egly, Driver, and Rafal (1994) included features of both exogenous and endogenous cues: On the one hand, like an exogenous cue, it was a peripherally presented luminance change (abrupt onset and offset), which should have automatically and directly captured attention. On the other hand, like an endogenous cue, it was highly predictive of target location (75% validity), so it might have induced a voluntary orientation of attention as well. To compare the two types of cues in a more controlled manner, Macquistan (1997) used a peripheral–exogenous cue that was not predictive of target location and a traditional, centrally presented endogenous arrow cue that had 75% validity. (He also changed the task to a discrimination task in which participants indicated whether a small equilateral triangle was pointing up or down.) The results were quite clear: A significant 12-ms object-based effect was obtained with the peripheral–exogenous cue ($n = 47$), but no such effect (0 ms) was obtained with the central–endogenous cue ($n = 47$). As mentioned earlier, similar failures to find an object-based effect with central arrow cues (but no such failures with exogenous cues) have been reported by Neely and Dagenbach (1996), Dagenbach et al. (1997), and Arrington, Dagenbach, et al. (2000).

Such results led Macquistan (1997) and others to speculate that exogenously controlled attention might be inherently object based and endogenously controlled attention inherently space based (see the General Discussion). We propose, however, an alternative explanation of the pattern that is not tied to the endogenous and exogenous modes of attentional orienting per se but, rather, to a postulated difference in the spatial extent of the initial focus of attention that is adopted in the two cuing conditions. Arguably, the most reasonable strategy for participants to adopt in the exogenous

[1] It is generally held that attention in the Egly, Driver, and Rafal (1994) task involves "grouped location" or "grouped array" selection (Vecera, 1994), which is object based in the sense that attention is sensitive to object boundaries (e.g., the contours of the rectangles) but is spaced based in the sense that what is selected (processed or navigated more efficiently) is a bounded region of space and the object parts or features contained therein. Stronger definitions of *object-based attention* reserve the term for situations in which attention selects object features from spatially invariant, "object-centered" representations (Vecera & Farah, 1994; but see Kramer, Weber, & Watson, 1997). In keeping with common usage, in this article the term *object-based attention* should be read as *grouped spatial-array attention*, unless stated otherwise.

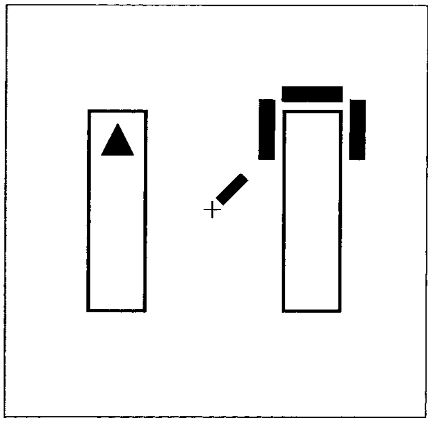

Figure 1. Superimposed representation of the stimuli used in Macquistan (1997) and the present study. On any given trial, either a peripheral–exogenous (right) or a central–endogenous (middle) cue was presented, with the target triangle (left) appearing after (coincidental with) cue offset. Both cue and target could appear in any of four possible display locations. (Note that the stimuli are not drawn to scale.)

cue condition is to spread their attention broadly over both rectangles while waiting for the target to appear (see Figure 2A; cf. Lavie & Driver, 1996). If this is so, the orienting to the exogenous cue would be initiated while the rectangle objects are actively being held within the focus of attention. By contrast, participants in the endogenous cue condition are likely to focus their attention more narrowly on the central fixation area, both while waiting for the central arrow cue to appear and while processing the direction of the arrow (see Figure 2B). In this case, the rectangle objects would not be encompassed within the focus of attention when the endogenous shift of attention is initiated. Essentially, the preparation for and processing of the endogenous arrow cue would create a state of *inattention* (Mack & Rock, 1998) with respect to the rectangle objects. If the rectangle object representations are thereby made unavailable when the endogenous orientation is initiated (or at least degraded to the point that they can no longer guide the allocation of attention), the narrow attentional spotlight would have to be moved spatially to the cued location (see Figure 2C). According to this explanation, the robustness of object-based effects with exogenous cues versus the relative fragility of such effects with endogenous cues does not stem from any inherent difference between the exogenous and endogenous modes of attentional orienting. Rather, it stems from a confound between the type of cue (endogenous vs. exogenous) and the focus of attention (narrow vs. spread) before, during, and after the processing of that cue.

Lavie and Driver (1996) proposed a similar role for attentional focus in modulating object-based effects. In their study, object-based effects were observed in a speeded matching task requiring comparison of two targets that could appear on one or both of two overlapping objects (crossed lines). The effect was eliminated, however, when attention was prefocused spatially by a (predictive) peripheral cue, “implying that object-based selection may only operate within spatially attended regions” (Lavie & Driver, 1996, p. 1238; but see Lamy, 2000; Law & Abrams, 2002). Despite the similarity of their proposal and ours, Lavie and Driver’s specific finding appears to conflict with the general results from the double-rectangle cuing paradigm, in which robust object-based effects are obtained precisely when peripheral cues are used. The possible resolution of this paradox, and some important differences between the two proposals, are addressed in the General Discussion.

A straightforward implication of our hypothesis regarding the role of attentional focus in modulating object-based effects in the double-rectangle cuing paradigm is that object-based effects would be expected to emerge under endogenous cuing if participants were to spread their attention diffusely across the rectangles while waiting for and then processing the endogenous cue (as is presumably the case under exogenous cuing). Conversely, we would expect object-based effects to be attenuated under exogenous cuing if attention were to be narrowly focused before cue onset. Both of these implications are examined in this article.

Overview of the Experiments

To serve as a baseline, in Experiments 1A and 1B we replicated the pattern, reported by Macquistan (1997) and others, that peripheral–exogenous cuing yields a same-object advantage in the double-rectangle task (Experiment 1A), whereas central–endogenous cuing does not (Experiment 1B).

In Experiments 2–4, we examined whether object-based effects would be obtained with endogenous cues under conditions that encouraged an initially diffuse attentional setting: In Experiments 2A and 2B, we used two different types of auditory endogenous cues—cues that presumably allowed participants to spread their attention widely (over the rectangles) both before and during the

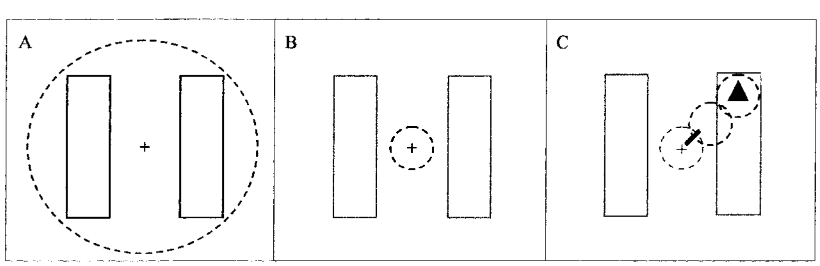

Figure 2. Postulated differences in the spatial extent of the initial focus of attention (area within dashed circle) between peripheral–exogenous cue trials (A) and central–endogenous cue trials (B). C: Endogenous spatial orienting of attention to the cued target location following focused attention to the central cue (assuming that the rectangle object representations are no longer perceptually viable).

processing of the cue. In Experiment 3, we used the same central arrow cue as in Experiment 1B, but here we instructed the participants to spread their attention over the rectangles while waiting for and processing the cue. In Experiment 4, peripheral-cue and central-arrow-cue trials were randomly mixed within blocks, so that the most expedient strategy would be to adopt a common, spatially diffuse attentional setting for all trials. As reported later, in all of these experiments, significant object-based effects were obtained under endogenous cuing.

In Experiments 5 and 6, we took the opposite approach, examining whether object-based effects would be attenuated under conditions that encouraged a narrow initial focus of attention. In Experiment 5, object-based effects were attenuated under peripheral–exogenous cuing when participants were required to attend to a small, centrally presented go/no-go cue prior to peripheral- (orienting-) cue onset. In Experiment 6, the same go/no-go cue was used to attenuate the object-based effect that had been obtained earlier under auditory endogenous cuing in Experiment 2B. Taken together, the results of these experiments suggest that the initial focus of attention plays a critical role in modulating object-based effects under both endogenous and exogenous cuing.

Experiment 1: Replication of Macquistan (1997)

The primary purpose of Experiment 1 was to establish a baseline in which object-based effects are present under peripheral–exogenous cuing but absent under central–endogenous cuing. We used Macquistan's (1997) version of the double-rectangle task, described earlier (see Figure 1). Experiments 1A and 1B were replications of the exogenous and the endogenous cue conditions of that study, respectively.

Method

Participants

Forty undergraduate students at the University of Haifa, Haifa, Israel, 20 in the exogenous cue condition (Experiment 1A) and 20 in the endogenous cue condition (Experiment 1B), participated in the experiment for payment (NIS 25, about $6, for a 45-min session). All participants had normal or corrected-to-normal vision.

Apparatus and Stimuli

The experiments were conducted with an IBM-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.

Both the stimuli and the procedure were modeled as closely as possible after Macquistan (1997). Examples of the stimuli and the two types of cues are shown in Figure 1. The stimuli were dark gray on a light background. 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. Two types of cues were used. The exogenous cue (Experiment 1A) consisted of three thick lines forming a fragmented C or U shape around the end of one of the rectangles (i.e., around one of the four possible target locations). Each line was 0.6° wide and 2.2° long and was separated from the sides of the object by 0.6°. The endogenous cue was a thick line segment subtending 1.2° in length and 0.4° in width, with one end 0.5° from fixation, oriented at 45°, 135°, 225°, or 315° from vertical (i.e., pointing to one of the four possible target locations).

Procedure

Participants were tested individually. The procedures for the two cuing conditions (Experiments 1A and 1B) were identical, except as noted below. Upon arriving at the experiment, participants received a verbal description of their task, and any questions that they had were answered. The importance of maintaining eye fixation throughout each trial was stressed. Participants were then given a block of practice trials that were identical to the experimental trials, during which the experimenter (Menahem Yeari) 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. This was followed by two blocks of experimental trials, with 192 trials in each block.

Each trial began with a blank screen for 1.5 s, and then the fixation cross appeared at the center of the screen. After 0.5 s the rectangles appeared, oriented horizontally or vertically with equal probability, and they remained on the screen throughout the trial. After the rectangles had been on the screen for 1 s, a spatial precue was presented, which differed between the two experiments.

Experiment 1A. The exogenous cue, used in Experiment 1A, was equally likely to appear at either end of either rectangle for a duration of 100 ms. 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, regardless of the cue location (i.e., the cue was not predictive of the target location). The participants' task was to indicate, by a keypress, the orientation of the target triangle (up or down). Participants were instructed to respond as quickly as possible without making errors.

Note that 25% of the trials were *valid-cue* trials (the target appeared in the cued location), and the remaining 75% of the trials were divided equally among three different types of *invalid-cue* trials: *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), and *far-location* trials (the target appeared at the far end of the opposite rectangle—diagonally opposite the cued location). As in Macquistan (1997), the far-location trials were included to prevent any overall correlation between the cue and target locations, but they are not germane to the analyses. The critical comparison is between the same-object and (equidistant) different-object invalid-cue trials, in which the target locations were equally distant from the cued location.

Experiment 1B. Endogenous-cue trials differed from exogenous-cue trials in three ways: First, the cue was a centrally displayed line segment (arrow) pointing to one of the four possible target locations. Second, the cue was displayed for 300 ms instead of 100 ms prior to target onset (i.e., the cue–target stimulus onset asynchrony [SOA] was 300 ms rather than 100 ms). Finally, the cue was generally predictive of the target's subsequent location: 80% of the trials (153 in each block) were valid-cue trials, and the remaining trials (39 in each block) were divided equally between the three invalid-cue conditions (and again, of these, only the equidistant different-object and same-object conditions are pertinent).[2]

Results

Mean correct response latencies and error rates were calculated for each participant in each of the three relevant cue–target con-

[2] Macquistan (1997) used an endogenous cue with 75% validity. Our use of a cue with 80% validity was due to an oversight, which, for the sake of consistency, was maintained throughout the experiments reported in this article.

ditions: validly cued targets, invalidly cued same-object targets, and invalidly cued (equidistant) different-object targets.[3] The latency means were trimmed by omitting any observations that fell more than 2.5 standard deviations above or below the mean for that particular cell (less than 2.5% of the trials). The trimmed mean latencies for Experiments 1A and 1B are presented in Figure 3. The accuracy results are presented below. All analyses were planned ANOVA contrasts, unless otherwise specified.

Experiment 1A: Peripheral–Exogenous Cuing

First, regarding accuracy, the mean error rates were 2.5%, 3.5%, and 2.2% for the valid, same-object, and different-object conditions, respectively. The planned comparison of the valid-cue condition versus the two invalid-cue conditions did not yield a significant difference, $F(1, 19) = 1.27$. However, on invalid-cue trials, there were marginally more errors in the same-object condition than in the different-object condition, $F(1, 19) = 4.01$, $p < .06$, which, given the latency results reported next, raises the possibility of a speed–accuracy trade-off. To examine this possibility, we calculated the within-subject correlation between RT and accuracy for each participant across all experimental trials (excluding the uncued far-location trials) and across the invalid-cue trials only. These averaged −.06 ($SD = .16$) for all trials and −.05 ($SD = .16$) for the invalid-cue trials. Thus, if anything, shorter latencies were weakly associated with greater accuracy within individual participants, both overall and on invalid-cue trials, allaying concerns about a speed–accuracy trade-off.

Turning now to the latency results, a planned comparison of the valid-cue condition versus the two invalid-cue conditions yielded a significant validity effect: Targets appearing in the cued location were responded to faster (593 ms) than were targets appearing in uncued locations (615 ms), $F(1, 19) = 10.35$, $p < .01$. Thus, the peripheral cue was effective in capturing attention. In addition, a significant object-based effect was observed: Invalidly cued targets appearing on the same rectangle as the cue were discriminated faster (609 ms) than were equally distant targets appearing on the opposite rectangle (621 ms), $F(1, 19) = 6.65$, $p < .05$. This 12-ms same-object advantage closely parallels the 12-ms advantage observed in Macquistan (1997).

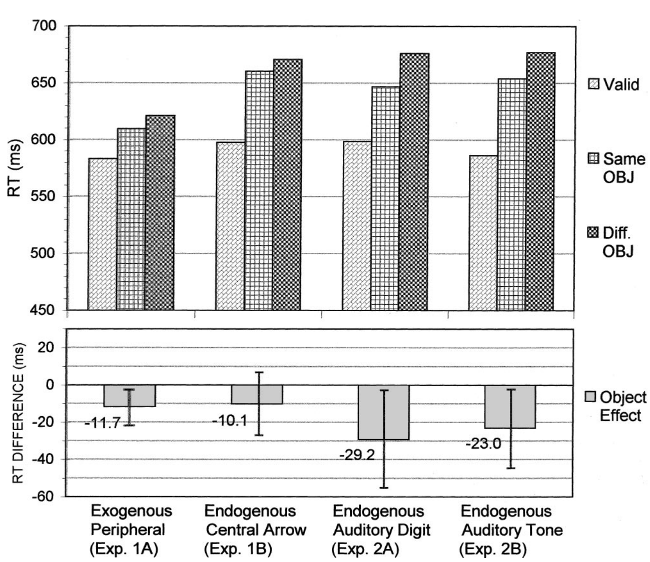

Figure 3. Latency results from Experiments (Exp.) 1 and 2. Top panel: Mean response latencies for each experiment and subexperiment, presented as functions of cue–target relation (Valid = valid cue; Same OBJ = invalid cue, target in same-object location; Diff. OBJ = invalid cue, target in equidistant different-object location). Bottom panel: Mean object effects (same-object response time [RT] minus different-object RT) for each experiment. The error bars represent 95% confidence intervals for the object effect ($n = 20$ for each experiment).

Experiment 1B: Central–Endogenous Cuing

Beginning again with accuracy, the mean error rates under endogenous cuing were 2.3%, 5.8%, and 3.8% for the valid-cue, same-object, and different-object conditions, respectively. The planned comparison of the valid-cue condition versus the two invalid-cue conditions indicated that significantly more errors were made for invalidly cued targets than for validly cued targets, $F(1, 19) = 13.45$, $p < .01$, and again there were marginally more errors in the same-object invalid-cue condition than in the different-object invalid-cue condition, $F(1, 19) = 2.71$, $p < .12$. Again, for each participant, the within-subject correlations between RT and accuracy across all experimental trials (excluding the uncued far-location trials) and across the invalid-cue trials only were calculated. These averaged −.01 ($SD = .11$) for all trials and .02 ($SD = .13$) for the invalid-cue trials. Thus, there did not appear to be a relationship between individual participants' RTs and accuracy, allaying concerns about a speed–accuracy trade-off.

With regard to the latency results, the planned comparison of the valid-cue condition versus the two invalid-cue conditions again yielded a significant validity effect: Targets appearing in the cued location were discriminated faster (598 ms) than were targets appearing in the two uncued locations (665 ms), $F(1, 19) = 43.11$, $p < .01$. Clearly, participants were making use of the central arrow cue to orient attention. Under this type of cuing, however, there

[3] Although the results regarding the far-location (different-object) targets are not germane to the questions addressed in this article, they may be of interest to some readers. For that reason, the mean (trimmed) response time (RT) for that target type and significant differences (by simple contrasts) from the three other target types (cue–target relations) are presented here for each of the reported experiments. For Experiment 1A, $M = 696$ ms, which was significantly slower than those for all other target types; for Experiment 1B, $M = 620$ ms, which was significantly slower than that for validly cued targets only; for Experiment 2A, $M = 671$ ms, which was significantly slower than that for validly cued targets only; for Experiment 2B, $M = 668$ ms, which was significantly slower than that for validly cued targets only; for Experiment 3, $M = 604$ ms, which was significantly slower than that for validly cued targets only; for Experiment 4 (endogenous cue), $M = 572$ ms, which was significantly slower than those for validly cued targets and uncued same-object targets only; for Experiment 4 (exogenous cue), $M = 582$ ms, which was significantly slower than those for validly cued targets and uncued same-object targets only; for Experiment 5A, $M = 740$ ms, which was significantly slower than that for validly cued targets only; for Experiment 5B, $M = 550$ ms, which was significantly slower than those for validly cued targets and uncued same-object targets only; for Experiment 6, $M = 725$ ms, which was significantly slower than that for validly cued targets only.

was no difference in the response latencies between invalidly cued targets appearing on the same rectangle (660 ms) and those appearing on the opposite rectangle (670 ms), $F(1, 19) = 1.43$, $p = .25$. As expected, a significant object-based effect was not observed in this experiment.

Discussion

The results of Experiments 1A and 1B appear to replicate the pattern reported by Macquistan (1997) and others: A same-object advantage in response latency was found under peripheral–exogenous cuing but not under central–endogenous cuing. Note, however, that the sizes of the latency difference between same-object and different-object conditions in the two experiments (12 ms and 10 ms in Experiments 1A and 1B, respectively) are quite similar. In fact, as revealed by the 95% confidence intervals for the object effect in the two experiments (see Figure 3), the difference between the two experiments is expressed primarily in the variability of the latency difference between the same-object and different-object conditions rather than in the mean: The size of the object effect was far more variable under endogenous cuing ($SD = 37.7$ ms) than it was under exogenous cuing ($SD = 20.3$ ms; this difference significant by Levene's test for homogeneity of variance).

The large variance in the endogenous cuing experiment and the resulting difference in the amount of variance observed in the two experiments, while posing a troubling statistical problem, also raise a potentially interesting substantive issue: Could the difference in the variability of the object effect be diagnostic of differences in the variability of the attentional-focusing processes under endogenous and exogenous cuing? The results of subsequent experiments suggest that variability in the size of the object-based effects obtained under different cuing conditions may in fact reflect—at least in part—variability in the initial focus of attention under the different cuing conditions. With regard to the statistical problem, heterogeneity of variance between cuing conditions requires the use of statistical tests with reduced power to detect differences in the size of the object-based effects between experiments, a problem that is compounded by the large variance in Experiment 1B and the relatively small sample sizes ($n = 20$ per group) for between-subjects comparisons.[4]

Our approach to this problem is two-fold: First, we continue to evaluate the fit between the results and the predictions of the attentional-focusing hypothesis in a qualitative manner, examining whether significant object-based effects are observed when they are expected to be observed and not observed otherwise. Across all of the reported experiments, 10 such predictions were made—7 in which object-based effects were expected and 3 in which they were not expected—all of which were confirmed. Use of either combinatorial mathematics or a binomial test to calculate the chance probability of successfully predicting 10 out of 10 such binary outcomes (7 significant and 3 not significant) yields $p < .01$ (see the General Discussion). Second, after all of the experiments have been reported, an overall analysis is conducted to compare the difference between the size of the object-based effect obtained in the seven experiments (cuing conditions) in which such an effect was expected and the size of the effect in the remaining experiments, in which no such effect was expected. This analysis verifies that the difference is statistically reliable.

Experiment 2: Object-Based Attention Under Auditory Endogenous Cuing

Experiment 1 established a baseline condition in which a significant same-object advantage was observed under peripheral–exogenous cuing but not under central–endogenous cuing. The aim of Experiment 2 was to examine whether a reliable same-object advantage would emerge under endogenous cuing when a different type of endogenous cue was used, which, like the peripheral–exogenous cue, allowed attention to be spread across the rectangles while participants waited for and processed the cue.

For this purpose, we used an auditory mode of presentation: In Experiment 2A, each of the four possible target locations was designated by a spoken digit from *1* to *4*; in Experiment 2B, each location was designated by a high- or low-pitched tone presented to either the left or right ear. A special practice session was added at the beginning of each experiment to familiarize participants with the cue-location mappings.

Method

Participants

Forty undergraduate students at the University of Haifa, 20 in the auditory-digit cue condition (Experiment 2A) and 20 in the auditory-tone cue condition (Experiment 2B), participated in the experiment for payment (NIS 35, about $8, for a 1-hr session). All participants had normal or corrected-to-normal vision.

Apparatus, Stimuli, and Procedure

The apparatus, stimuli, and procedure were identical to those used in Experiment 1B, with the following differences:

Cue presentation. In Experiment 2A, the cues were four numbers spoken in Hebrew in a male voice (the numbers *1* to *4*: "ehad," "shtayim," "shalosh," and "arbah"), each recorded with an acoustic duration of 1 s and played over computer-attached headphones. The target was presented 300 ms after acoustic offset (cue–target SOA = 1,300 ms). Each number designated a particular potential target location, with *1* designating the top left location, continuing from *2* through *4* in a clockwise fashion. The same cue-location mapping applied regardless of whether the rectangles were presented vertically or horizontally.

In Experiment 2B, the cues were two computer-generated tones: a pure low-frequency tone (220 Hz) and a pure high-frequency tone (880 Hz), presented to either the left or right ear over computer-attached headphones. Each tone was presented with an acoustic duration of 200 ms and a cue–target SOA of 800 ms. Each tone–ear combination designated a particular potential target location, with the high tone mapped onto the upper two locations, the low tone mapped onto the lower two locations, the left ear mapped onto the left two locations, and the right ear mapped onto the right two locations. Again, the same cue-location mapping applied regardless of whether the rectangles were presented vertically or horizontally.

Cue practice task. To familiarize the participants with the cue-location mappings, a special practice task was added at the start of both Experiments 2A and 2B (before the practice for the experimental task). Each trial

[4] With $n = 47$ participants in each cuing condition, Macquistan (1997) did find a significant difference in the object-based effect between the endogenous and exogenous cuing conditions using a nonparametric, Wilcoxon signed rank test, in addition to observing a nonsignificant effect in the endogenous cuing condition.

in this task began in the same way as did the experimental trials (i.e., fixation cross, rectangles, auditory cue). On hearing the cue, however, the participants' task was to move a small joystick as quickly as possible in one of four diagonal directions toward the location indicated by the cue (upper left, upper right, lower left, or lower right). The joystick was fitted within a box with four grooves that allowed only these four directions of movement. Immediately following the participant's response, a green square was presented for 600 ms in the cued location, and, if the participant had moved the joystick elsewhere, a red square was also presented at the incorrectly designated location. The participants were allowed up to 1 s to respond, otherwise a short beep was sounded and the green feedback square appeared in the cued location. Each participant performed one block of 120 such trials, which was sufficient for all participants to achieve fast and accurate performance.

Results

As before, mean correct response latencies and error rates were calculated for each participant for each of the three types of target: validly cued targets, invalidly cued same-object targets, and invalidly cued different-object targets (near condition only). Trimming the means (those above or below 2.5 standard deviations per cell) removed less than 2.6% of the observations. The latency results for Experiments 2A and 2B are presented in Figure 3 (above).

Experiment 2A: Auditory-Digit Cues

The mean error rates were 4.6%, 5.6%, and 6.5% for the valid-cue, same-object, and different-object conditions, respectively. Neither the planned comparison of the valid-cue condition versus the two invalid-cue conditions, $F(1, 19) = 2.21$, nor the comparison of the same-object and different-object invalid-cue conditions, $F(1, 19) = 1.15$, were significant. In any case, the error-rate differences mirrored the pattern of latency differences in this experiment. Thus, a speed–accuracy trade-off is not a concern.

Turning now to the latency data, the planned comparison of the valid-cue condition versus the two invalid-cue conditions yielded a significant validity effect: Targets appearing in the cued location were responded to faster (598 ms) than were targets appearing in the two other locations (661 ms), $F(1, 19) = 19.07$, $p < .01$. Clearly, participants were making use of the auditory-digit cue to orient attention. In addition, under this type of endogenous cuing, invalidly cued same-object targets were discriminated faster (647 ms) than were different-object targets (676 ms)—a 29-ms same-object advantage, $F(1, 19) = 4.92$, $p < .05$.

Experiment 2B: Auditory-Tone Cues

The mean error rates were 3.4%, 4.6%, and 4.4% for the valid-cue, same-object, and different-object conditions, respectively. Neither the planned comparison of the valid-cue condition versus the two invalid-cue conditions, $F(1, 19) = 2.40$, nor the comparison of the same-object and different-object invalid-cue conditions ($F < 1$) were significant. Thus, a speed–accuracy trade-off is not a concern.

Turning now to the latency data, targets appearing in the cued location were responded to faster (586 ms) than were targets appearing in the two uncued locations (666 ms), $F(1, 19) = 13.43$, $p < .01$. Clearly, participants were making use of the auditory-tone cue to orient attention. In addition, here too, invalidly cued same-object targets were discriminated faster (654 ms) than were different-object targets (677 ms)—a 23-ms same-object advantage, $F(1, 19) = 4.68$, $p < .05$.

Discussion

As predicted, because they did not encourage focused attention to the center of the display, the auditory cues yielded significant endogenous object-based effects. As mentioned earlier, Abrams and Law (2000) also reported object-based effects under endogenous cuing, but they were unable to explain why their results differed from those of other studies that had failed to find such effects. In addition, Dagenbach et al. (1997) reported one experiment (out of eight) in which object-based effects were obtained under endogenous cuing—when linguistic auditory cues ("top-right," "bottom-left," and so forth) were used. This finding was not theory driven (and apparently did not replicate in their study), so they too lacked an explanation for the seeming anomaly.

In contrast, the present experiment and findings were driven by the hypothesis that the initial focus of attention is a critical variable modulating object-based effects under endogenous cuing. Was the opportunity to keep attention spread over the rectangles while processing the cue in fact responsible for the object-based effects in this experiment? Although direct evidence is lacking, we can discredit some alternative explanations. In searching for an explanation for their anomalous auditory-cue result, Dagenbach et al. (1997) raised the possibility that linguistic endogenous cues might induce object-based attention through left-hemisphere activation (cf. Egly, Rafal, Driver, & Starrveveld, 1994). However, in our study, similar results were obtained with spoken digits (Experiment 2A) and auditory tones (Experiment 2B), the latter cues being nonlinguistic. Also, the fact that the results replicated with different cues and SOAs suggests that the effect was relatively robust. Of course, one obvious alternative explanation that must be considered is that the auditory mode of cuing itself is responsible for inducing object-based attention. This possibility is discredited in the following experiment.

Experiment 3: Object-Based Attention With Central Cuing Under Explicit Instructions to Spread Attention

One way to examine whether object-based attention with endogenous cuing is conditional on the auditory mode of cue presentation would be to design a visual endogenous cue that could be processed with spatially spread attention (e.g., the color of the display background or of a surrounding frame). That approach, however, would be problematic, because attending to a spatially spread visual cue could affect the perceptual organization of the display in unpredictable ways (e.g., the rectangles might become background; cf. Peterson & Gibson, 1991; Tsal & Kolbet, 1985). The approach we took in this experiment was simpler. We had participants perform the same endogenous cuing task as used in Experiment 1B (with the same central arrow cue), but this time we explicitly instructed them to avoid focusing on the central arrow when it appeared. They were instructed instead to keep their attention spread across the area of the two rectangles (because that was where the target would eventually appear) and to try to pick up the direction of the arrow cue without breaking that spread. The idea was to encourage the participants to do exactly what we believe that they do when waiting for the target to appear under peripheral–exogenous cuing (Experiment 1A).

At first blush, it might seem that such instructions (to the extent that they can be executed) actually force the participants to generate an object-based effect. Note, however, that the instructions are to spread attention over both rectangles while waiting for and processing the central arrow cue. This in itself would not impart an advantage to one rectangle (i.e., the one containing the cued location) over the other. Hence, the finding of a same-object advantage in this experiment would imply that attention was deployed specifically to one of the rectangles after the cue was interpreted—an object-based deployment that presumably was made possible or facilitated by the initially distributed attentional focus but was not called for by the instructions.

Method

Participants

Twenty undergraduate students at the University of Haifa participated in the experiment for payment (NIS 25, about $6, for a 45-min session). All participants had normal or corrected-to-normal vision.

Apparatus, Stimuli, and Procedure

The apparatus, stimuli, and procedure were identical to those used in Experiment 1B, except for the addition of explicit instructions regarding the spread of attention and the processing of the central arrow cue. The following were the main changes and additions to the instructions:

During the initial explanation of the course of events in each trial, the following two sentences were added (in Hebrew):

1. "From the moment they appear, try to spread and lock your 'concentration' over the area of the rectangles, without moving your eyes."

2. "Try to pick up the direction of the arrow [cue] without focusing your gaze on it, rather, continue to concentrate on the area of the rectangles."

As a final summary, at the end of the instructions, the following paragraph was added (in Hebrew):

> It is important that you try to maximize your performance. In order to do this, we know from previous experience that you should lock your attention on the area of the rectangles, so that you will be ready to detect the appearance of the target triangle in one of their corners as fast as possible. Of course, it is important to take advantage of the direction of the cue, that is, to be especially prepared for the target to appear in the corner pointed to by the arrow, but it is important to do this without moving your gaze or concentration to the cue itself. Therefore, try to pick up the direction of the arrow "by the way," and continue to concentrate on the area of the rectangles without interruption.

Results

As before, mean correct response latencies and error rates were calculated for each participant for each of the three target types: validly cued targets, invalidly cued same-object targets, and invalidly cued different-object targets (near condition only). Trimming the means (those above or below 2.5 standard deviations per cell) removed less than 2.4% of the observations. After the means were trimmed, the data from one participant were discarded because of excessively slow response latencies (more than 7 standard deviations slower than the overall mean of the other participants). The latency results for the remaining 19 participants in Experiment 3 are presented in Figure 4 (the baseline results of Experiments 1A and 1B are provided again for comparison, as are the results of subsequent Experiments 4A and 4B).

The mean error rates were 1.9%, 2.4%, and 2.0% for the valid-cue, same-object, and different-object conditions, respectively. Neither the planned comparison of the valid-cue condition versus the two invalid-cue conditions nor the comparison of the same-object and different-object invalid-cue conditions was significant (both Fs < 1). Thus, a speed–accuracy trade-off is not a concern.

With regard to the latency results, there was a significant validity effect: Targets in the valid-cue condition were responded to faster (540 ms) than were targets in the two invalid-cue conditions (599 ms), $F(1, 18) = 51.90$, $p < .001$. Clearly, participants were making effective use of the central arrow cue to orient attention, despite the diffuse-attention instructions. In addition, under these instructions, invalid-cue same-object targets were discriminated faster (592 ms) than were different-object targets (606 ms)—a 14-ms same-object advantage, $F(1, 18) = 6.12$, $p < .05$. As predicted, the diffuse-attention instructions were effective in eliciting a significant object-based effect, with the same endogenous arrow cue that had failed to yield such an effect earlier under standard instructions (Experiment 1B).

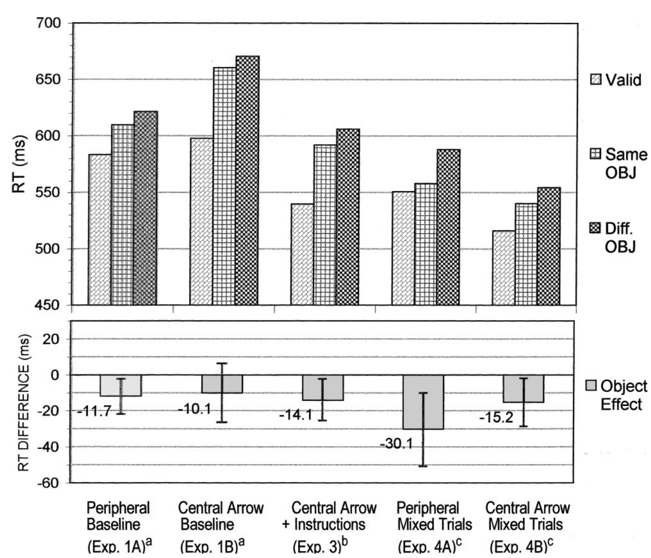

Figure 4. Latency results from Experiments (Exp.) 3 and 4 and baseline results from Experiments 1A and 1B (for comparison). Upper panel: Mean response latencies for each experiment and subexperiment, presented as functions of cue–target relation (Valid = valid cue; Same OBJ = invalid cue, target in same-object location; Diff. OBJ = invalid cue, target in equidistant different-object location). Lower panel: Mean object effects (same-object response time [RT] minus different-object RT) for each experiment. The error bars represent 95% confidence intervals for the object effect ([a]$N = 20$; [b]$N = 19$; [c]$N = 12$).

Discussion

The results of Experiment 3 provide additional support for the critical role of attentional focus in modulating object-based attention under endogenous cuing. The only difference between the procedure of the present experiment and that of Experiment 1B was the instruction to avoid focusing attention on the central arrow cue and instead to spread attention over the rectangles while waiting for and processing the cue. This focusing difference alone yielded the expected results.

Note that the significant 14-ms same-object advantage in this experiment is again of approximately the same magnitude as the nonsignificant 10-ms difference observed in Experiment 1B. Apparently, one effect of the diffuse-attention instructions was to reduce the variability of the same-object advantage ($SD = 37.7$ in Experiment 1B vs. 24.8 in Experiment 3; marginally different by a Levene test for homogeneity of variance, $p = .07$). This lends some credence to the idea raised earlier, in comparing the results of Experiments 1A and 1B, that differences in the initial focus of attention under central endogenous cuing may be a source of (error) variance in the observed object-based effect: Giving participants explicit instructions about how to spread their attention should reduce variability in the initial focus of attention, which in turn should reduce the variability in the same-object advantage.

A further implication of the findings is that the focus of attention—and, consequently, object-based attention—can be controlled. It was not a foregone conclusion that participants would be able or willing to execute the special focusing instructions and still make effective use of the cue in this experiment. The fact that they could, inferred from the enhancement of the same-object advantage (and of overall performance; see below), while still maintaining a cued-location advantage, implies that focusing strategies, as well as random variance in attentional focusing, can potentially underlie differences in both the magnitude and the statistical significance of object-based effects under endogenous cuing.

It is interesting to note that the overall level of performance in Experiment 3, in terms of both latencies and error rates, was markedly better than in any of the preceding experiments. This suggests that the diffuse-attention strategy for picking up the direction of the central arrow cue was in fact a more efficient processing strategy (as the participants were led to believe). If so, one can wonder why many of the participants in Experiment 1B, for instance, apparently did not choose this strategy on their own. Perhaps participants would spontaneously adopt a diffuse-attention strategy to process the central arrow cue if the advantage of doing so was more pronounced (cf. Erev & Gopher, 1999). To shed light on this issue and to provide further evidence for the postulated relationship between spread of attention and object-based effects, in the following experiment we created conditions in which a diffuse attentional setting was clearly advantageous, even under central–endogenous cuing.

Experiment 4: Object-Based Attention With Central Cues Resulting From Strategic (De)focusing

The aim of Experiment 4 was to examine whether task structure could be used to elicit the spontaneous adoption of a diffuse-attention strategy under central–endogenous cuing and, as a consequence, to induce object-based attention.[5] In this experiment, central–endogenous-cue trials and peripheral–exogenous-cue trials were randomly mixed within blocks. Because participants did not know at the beginning of each trial which type of cue would be presented, we expected them to adopt an initial attentional setting that would be efficient for either type of cue.

As discussed earlier, we assume that the most efficient strategy for performance on peripheral–exogenous-cue trials is to spread attention broadly across the rectangles in preparation for the target (which can appear in any of the four designated locations with equal likelihood). At the same time, the results of Experiment 3 indicated that not only is it possible to process the central arrow cue using such a strategy, it is perhaps even more efficient than focusing attention more narrowly on the arrow cue. In this experiment, therefore, we expected a spatially spread attentional setting to be adopted and maintained at the beginning of each trial, which, according to the attentional-focusing hypothesis, should yield a same-object advantage for both the endogenous and the exogenous cuing conditions.

Method

Participants

Twelve undergraduate students at the University of Haifa participated in the experiment for payment (NIS 35, about $8, for a 1-hr session). All participants had normal or corrected-to-normal vision.

Apparatus, Stimuli, and Procedure

The apparatus, stimuli, and procedure (including stimulus durations and SOAs) were identical to those used in Experiments 1A (peripheral–exogenous cues) and 1B (central–endogenous cues), except for the following changes:

1. Four blocks of experimental trials, each containing 64 exogenous-cue trials (like Experiment 1A) and 96 endogenous-cue trials (like Experiment 1B) were presented to each participant, for a total of 224 exogenous-cue trials and 384 endogenous-cue trials. For the exogenous-cue condition (25% validity), this produced 64 trials in each of the four possible cue–target relations (valid cue, same object, different object near, and different object far). For the endogenous-cue condition (80% validity), this produced 309 valid-cue trials and 25 trials in each of the three invalid-cue conditions. (As for the earlier experiments, the far-location different-object trials are not included in the analyses.)

2. Both exogenous- and endogenous-cue trials were presented in the initial block of practice trials (randomly mixed in approximately the same proportions as in the experimental trials). As before, the practice was terminated after 20 successive trials without eye movements.

3. Participants were told that either type of cue might appear on any given trial. As in Experiment 1, they were told only that on "peripheral flash" trials there would be no relationship between the location of the flash (cue) and the subsequent location of the target, whereas on "arrow" trials, the target would usually (but not always) appear in the designated location.

[5] We thank Marlene Behrmann for suggesting this experiment.

Results

Mean correct response latencies and error rates were calculated for each participant separately for each cue type and each of the three target types: validly cued targets, invalidly cued same-object targets, and invalidly cued different-object targets (near condition only). Trimming the means (those above or below 2.5 standard deviations per cell) removed less than 2.0% of the observations.

The mean error rates on exogenous-cue trials were 2.9%, 3.8%, and 4.7%, for the valid-cue, same-object, and different-object conditions, respectively. The corresponding mean error rates on endogenous-cue trials were 4.1%, 3.8%, and 4.6%. For both cue types, fewer errors were made on valid-cue trials than on the two types of invalid trials combined, though the planned comparison conducted across the two cue types was not significant ($F < 1$; also $F < 1$ for the interaction with cue type). For both cue types, fewer errors were made on same-object trials than on different-object trials, though the planned comparison across the two cue types did not reach significance, $F(1, 11) = 2.51$, $p < .15$ ($F < 1$ for the interaction with cue type). In any case, the error-rate differences were in the same direction as the latency differences, so a speed–accuracy trade-off is not a concern.

The latency results for the exogenous- and endogenous-cue conditions are presented in Figure 4 (above). We begin with the exogenous-cue condition. First, there was a significant validity effect: Targets appearing in the cued location were responded to faster (551 ms) than were targets appearing in the two uncued locations (573 ms), $F(1, 11) = 13.24$, $p < .01$. Thus, the peripheral–exogenous cue continued to capture attention in this experiment. Second, a significant 30-ms same-object advantage was found, $F(1, 11) = 10.93$, $p < .01$. With regard to the endogenous cue condition, here validly cued targets were also responded to faster (516 ms) than were invalidly cued targets (548 ms), $F(1, 11) = 16.34$, $p < .01$. Thus, participants were apparently making use of the arrow cue on those trials in which it was presented. Moreover, as predicted, a significant same-object advantage (15 ms) was obtained, $F(1, 11) = 6.15$, $p < .05$.

An additional analysis was performed to examine possible short-term carryover effects from exogenous-cue trials to immediately subsequent endogenous-cue trials (or vice versa). For this analysis, each latency observation (after trimming) was classified according to the type of cue (exogenous or endogenous) that had been presented on the immediately preceding trial, and the means for each participant were recalculated with this factor included. An equivalent same-object advantage was found for exogenous-cue trials, whether preceded by an exogenous-cue trial (33 ms) or by an endogenous-cue trial (23 ms; $F < 1$). Also, an equivalent same-object advantage was found for endogenous-cue trials preceded by either an endogenous-cue trial (14 ms) or an exogenous-cue trial (15 ms; $F < 1$). We conclude that short-term carryover effects cannot explain the same-object advantage obtained with central endogenous cues in this experiment.

Discussion

The results of Experiment 4 bolster the hypothesis that focus of attention modulates object-based effects in the double-rectangle paradigm. Unlike in Experiment 3, no special instructions were given to the participants concerning how to focus their attention. Instead, implicit strategic considerations presumably induced the participants to adopt a common, widely spread attentional setting at the beginning of each trial, which would be effective regardless of the type of cue that ultimately appeared. This setting, in turn, yielded significant object-based effects for both exogenous and endogenous cues. It apparently also reduced variability in the object-based effect under central cuing compared with the standard central-arrow cue condition ($SD = 38$ ms in Experiment 1B vs. 21 ms here; significantly different by Levene's test for homogeneity of variance, $p < .05$). As discussed earlier, this might reflect a reduction in the variance of the initial spread of attention, though from this perspective, the relatively large variance in the exogenous object-based effect ($SD = 32$ ms) in this experiment is puzzling.

Of course, once again, the evidence for the role of attentional focus is indirect. However, if the difference between the results of this experiment and those of Experiment 1B did not stem from a change in attentional focus, what might account for it? The only difference between the two experiments is that in this experiment the endogenous arrow-cue trials were intermixed with the exogenous peripheral-cue trials, whereas in Experiment 1B they were not. Conceivably, one could posit the existence of some sort of object-based attentional priming that spread from the exogenous-cue trials to the endogenous-cue trials. Yet, the analysis of carryover effects from one trial to the next indicated that there was no carryover of object-based attention from an exogenous-cue trial to an immediately following endogenous-cue trial (or vice versa). One would have to posit, then, a cumulative priming of object-based attention emanating from the exogenous-cue trials to the endogenous-cue trials, without any additional priming taking place on adjacent trials. Given the overall pattern of results in Experiments 1–4, we believe that the attentional-focusing explanation of the results of Experiment 4 is more plausible, and certainly more parsimonious, than the object-based priming explanation.

Experiment 5: Eliminating Object-Based Attention Under Exogenous Cuing

Experiments 2–4 supported the attentional-focusing hypothesis by showing that under conditions expected to induce spread attention, endogenous cues—like exogenous cues—yielded robust object-based effects. We now turn to address the converse issue: Will inducing participants to adopt an initially narrow attentional focus prior to cue onset eliminate the object-based effect normally found under exogenous cuing?

To examine this question, we adapted the standard exogenous cue condition from Experiment 1A, adding a small, centrally presented go/no-go cue at the beginning of each trial. The go/no-go cue was a small gray (low-contrast) square, appearing together with and surrounding the fixation point. *Go* trials (in which the participant was instructed to respond as usual) were signaled by the continuous presentation of the go/no-go cue until the end of the trial, whereas *no-go* trials (in which the participant was instructed to refrain from responding) were signaled by the disappearance of the cue 200 ms before the onset of the exogenous cue. Thus, to correctly discriminate the go trials from the no-go trials, participants had to keep their attention focused at the center of the display (on the go/no-go cue) until the onset of the peripheral–exogenous orienting cue.

According to the attentional-focusing hypothesis, just as in the case of the central–endogenous arrow cue, focusing and maintaining attention on the central go/no-go cue should create a state of inattention (Mack & Rock, 1998) with respect to the two rectangles, degrading their object representations and, hence, attenuating or eradicating the object-based effect. In this experiment, however, there was a danger that focused attention to the center of the display would also prevent attentional capture by the abrupt onset of the peripheral–exogenous cue (cf. Theeuwes, 1991), undermining the effectiveness of the spatial cuing. We hoped that this would not be the case, because unlike in previous experiments in which attentional capture was prevented by focused attention, here the participants were not motivated to filter out interfering peripheral abrupt onsets. On the contrary, the task demanded that they be prepared to detect the abrupt onset of the target (triangle)—and, consequently, of the peripheral cue—while also attending to the go/no-go cue. In fact, both pretesting and the final experimental results yielded a significant and substantial peripheral cue-validity effect on go trials, which is a precondition for examining whether there is evidence of object-based attention.

Finally, as a check on whether the results of this experiment could be attributed to visual interference from the presence of the central square per se, a control condition was also included in which the central square appeared around the fixation cross but had no relevance to the task.

Method

Participants

Twenty-nine undergraduate students at the University of Haifa, 15 in the go/no-go condition (Experiment 5A) and 14 in the control condition (Experiment 5B), participated in the experiment for payment (NIS 30, about $6.50, for a 45-min session). All participants had normal or corrected-to-normal vision.

Apparatus, Stimuli, and Procedure

The apparatus, stimuli, and procedure were identical to those used in Experiment 1A (standard exogenous cuing), with the following differences (2–4 applying to Experiment 5A [go/no-go] only):

1. At the beginning of each trial, a gray (low-contrast) square, subtending 1.6° × 1.6°, with a line width of 0.09°, was presented together with and surrounding the central fixation cross. In Experiment 5A only, on one third of the trials (no-go trials), the central square disappeared 200 ms before the appearance of the exogenous cue. On the remaining trials (i.e., go trials only in Experiment 5A and all trials in Experiment 5B), the square remained in the display until the participant responded to the target.

2. The participants were instructed to respond to the target triangle (up or down) on trials in which the central square remained present (go trials) but to refrain from responding on trials in which the square disappeared (no-go trials).

3. Four blocks of experimental trials, each containing 96 go trials and 48 no-go trials (randomly mixed) were presented to each participant, for a total of 384 go trials (as in Experiment 1A) and 192 no-go trials.

4. Both go and no-go trials were presented in the initial block of practice trials. As before, the practice was terminated after 20 successive trials without eye movements.

Results

Experiment 5A (Go/No-Go Condition)

Mean correct response latencies (after trimming those above or below 2.5 standard deviations per cell: less than 1.7% of the data) and error rates on the go trials were calculated for each participant in each of the three cue–target conditions: validly cued targets, invalidly cued same-object targets, and invalidly cued different-object targets (near condition only). The percentages of *go errors* (go trials that were not responded to) and *no-go errors* (no-go trials that were responded to) were also calculated for each participant and then averaged. The mean latencies for Experiment 5A are presented in Figure 5, together with those from the control condition (Experiment 5B) and the results from Experiments 2B and 6 (for later comparison).

Regarding go/no-go accuracy, both go and no-go error rates were quite low (averaging 0.6% and 2.8%, respectively), indicating that the participants were attending to the central go/no-go cue. On go trials, the mean target-discrimination error rates were 0.6%, 1.6%, and 2.1% for the valid-cue, same-object, and different-object conditions, respectively. Fewer errors were made in the valid-cue condition than in the two invalid-cue, conditions, $F(1, 14) = 9.50$, $p < .01$, whereas the comparison of the same-object and different-object invalid-cue conditions was not significant, $F(1, 14) = 1.07$. Thus, a speed–accuracy trade-off is not a concern.

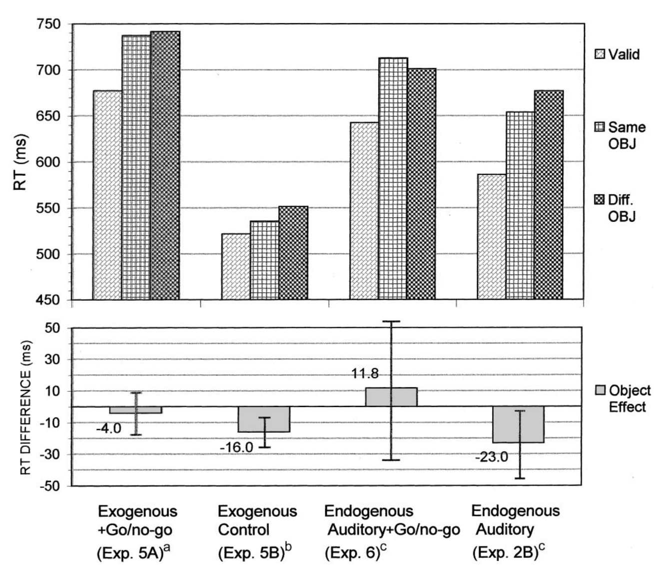

Figure 5. Latency results from Experiments (Exp.) 5 and 6, with results from Experiment 2B (for comparison with Experiment 6). Upper panel: Mean response latencies for each experiment and subexperiment, presented as functions of cue–target relation (Valid = valid cue; Same OBJ = invalid cue, target in same-object location; Diff. OBJ = invalid cue, target in equidistant different-object location). Lower panel: Mean object effects (same-object response time [RT] minus different-object RT) for each experiment. The error bars represent 95% confidence intervals for the object effect ([a]$N = 15$; [b]$N = 14$; [c]$N = 20$).

Turning now to the latency results, targets appearing in the cued location were responded to faster (677 ms) than were targets appearing in the two uncued locations (739 ms), $F(1, 14) = 34.76$, $p < .01$. Thus, despite the need to attend to the central go/no-go cue, the peripheral cue was effective in capturing attention. However, there was no difference between the response latencies to invalidly cued targets appearing on the same rectangle as the cue (737 ms) and response latencies to those appearing on the opposite rectangle (741 ms; $F < 1$). As predicted, there was no object-based effect observed with peripheral–exogenous cuing in this experiment.

Experiment 5B (Control Condition)

The purpose of Experiment 5B was to check whether the mere visual presence of the central square could be responsible for the elimination of the object-based effect under peripheral–exogenous cuing in Experiment 5A. In this experiment, the central square appeared around the fixation cross for the duration of each trial, but no mention of it was made to the participants (all trials were go trials). Hence, except for the presence of the square, this experiment is simply a replication of Experiment 1A. The mean correct response latencies (after trimming those above or below 2.5 standard deviations per cell) for each cue-target position are presented in Figure 5.

The mean error rates were 1.9%, 1.1%, and 1.6% for the valid-cue, same-object, and different-object conditions, respectively. Neither the planned comparison of the valid-cue condition versus the two invalid-cue conditions, $F(1, 13) = 3.42$, $p < .09$, nor the comparison of the same-object and different-object invalid-cue conditions, $F(1, 13) = 1.24$, *ns*, reached significance. Thus, a speed–accuracy trade-off is not a concern.

Regarding the latency results, targets appearing in the cued location were responded to faster (522 ms) than were targets appearing in the two uncued locations (543 ms), $F(1, 13) = 19.57$, $p < .01$. Thus, the peripheral cue was effective in capturing attention. Also, invalidly cued targets appearing on the same rectangle as the cue were responded to faster (535 ms) than were those appearing on the opposite rectangle (551 ms), $F(1, 13) = 15.37$, $p < .01$. As in Experiment 1A, but unlike in Experiment 5A, a significant object-based effect was observed.

Discussion

Can the robust object-based effect normally found under peripheral–exogenous cuing be eliminated by inducing participants to adopt a narrow initial attentional focus prior to cue onset? The answer is yes: When participants had to attend to a central go/no-go cue at the beginning of each trial (Experiment 5A), no object-based effect was observed. In the control experiment (5B), removing the need to attend to the cue reinstated the object-based effect. Again, although no direct measures of attentional focus are available, the simplest explanation is the one provided by the attentional-focusing hypothesis: Under peripheral–exogenous cuing, participants normally spread their attention across the rectangles while waiting for the target to appear (Experiments 1A, 4, and 5B), which facilitated the formation of viable rectangle-object representations prior to the movement of attention in response to the cue. However, requiring participants to focus their attention on the go/no-go cue until peripheral-cue onset (Experiment 5A) presumably prevented or impaired the formation of the rectangle-object representations, thereby preventing object-based attention. Thus, as with the purported connection between endogenous orienting and space-based attention, there would seem to be no inherent relation between exogenous orienting and object-based attention. Rather, whether or not object-based effects are observed under exogenous (and endogenous) cuing depends primarily on whether or not attention is spread or focused prior to the appearance of the cue.

Experiment 6: Eliminating Object-Based Attention Under Auditory Endogenous Cuing

In the preceding experiments, we used two complementary strategies to support the attentional focusing hypothesis: (a) enabling object-based attention under endogenous cuing by creating conditions in which participants were likely to adopt a diffuse attentional setting and (b) disabling object-based attention under exogenous cuing by adding a task in which participants had to adopt a narrowly focused attentional setting. In this final experiment, we combined both strategies, adding the go/no-go task (central go/no-go cue) used in Experiment 5A to the auditory endogenous cue that was used in Experiment 2B. If we are correct in assuming that the auditory endogenous cues used earlier (Experiments 2A and 2B) enabled object-based attention by allowing participants to spread their attention widely across the rectangles (rather than focus their attention on a central arrow cue), then requiring participants to focus anew on the central go/no-go cue should prevent the diffuse attentional setting, eliminating once again the object-based effect.

Method

Participants

Twenty-three undergraduate students at the University of Haifa participated in the experiment for payment (NIS 35, about $8, for a 1-hr session). All participants had normal or corrected-to-normal vision.

Apparatus, Stimuli, and Procedure

The apparatus, stimuli, and procedure were identical to those used in Experiment 2B (auditory-tone endogenous cuing), with the following differences:

1. At the beginning of each trial, a gray (low-contrast) square, subtending $1.6° \times 1.6°$, with a line width of 0.09°, was presented together with and surrounding the central fixation cross. On one third of the trials (no-go trials), the central square disappeared 200 ms before the appearance of the exogenous cue. On the remaining trials (go trials), the square remained present until the participant responded to the target.

2. The participants were instructed to respond to the target triangle (up or down) on go trials and to refrain from responding on no-go trials.

3. Four blocks of experimental trials, each containing 96 go trials and 48 no-go trials (randomly mixed) were presented to each participant, for a total of 384 go trials (as in Experiment 2B) and 192 no-go trials. Both go and no-go trials were presented in the

initial block of practice trials, which was terminated after 20 successive trials without eye movements.

Results

Mean correct response latencies (after trimming those above or below 2.5 standard deviations per cell: about 1.7% of the trials) and error rates on the go trials were calculated for each participant in each of the three cue–target conditions: validly cued targets, invalidly cued same-object targets, and invalidly cued different-object targets (near condition only). The percentages of go errors (go trials that were not responded to) and no-go errors (no-go trials that were responded to) were also calculated for each participant and then averaged. Two participants were dropped from the subsequent analyses due to inordinately high rates of no-go errors (23.3% and 30.9%, respectively, compared with a mean of 2.0% for the remaining participants), and one participant was dropped due to an inordinately high target-discrimination error rate on go trials (41.4% errors, compared to a mean of 2.8% for the remaining participants). The mean latencies for the 20 remaining participants are presented in Figure 5 (above), together with those from Experiment 2B (for comparison).

Regarding the go/no-go accuracy, except for the results for the two participants excluded on this basis, there were very few go errors (0.2% of go trials) or no-go errors (2.0% of no-go trials), indicating that the participants were paying attention to the central go/no-go cues. On go trials, the mean target-discrimination error rates were 2.5%, 2.3%, and 2.5%, for the valid-cue, same-object, and different-object conditions, respectively, with no significant differences (all Fs < 1). Thus, a speed–accuracy trade-off is not a concern.

Turning now to the latency results, targets appearing in the cued location were responded to faster (643 ms) than were targets appearing in the uncued locations (706 ms), $F(1, 19) = 8.55$, $p < .01$. Thus, despite the need to attend to the central go/no-go cue, the endogenous auditory cue was effective in guiding attention to the target location. However, there was no difference between the response latencies to invalidly cued targets appearing on the same rectangle (713 ms) and response latencies to those appearing on the opposite rectangle (701 ms; $F < 1$). As expected, unlike in Experiment 2B, there was no object-based effect observed with auditory cues in this experiment.

Discussion

Earlier, the results of Experiments 2A and 2B (endogenous auditory cues) were taken to indicate that unlike the standard central arrow cue (Experiment 1B), endogenous auditory cues encouraged participants to adopt an initially diffuse attentional setting, thereby yielding a relatively robust object-based effect. The results of Experiment 6 buttress that interpretation by showing that despite the auditory cuing, the object-based effect was prevented once more when an additional aspect of the task (attending to a go/no-go cue) required participants to narrow their initial attentional focus to the center of the display. If anything, there was a slight trend toward a different-object advantage in this experiment, though this was probably just a chance result stemming from the very large variance in the size of the object effect (see later discussion). Thus, in line with the attentional-focusing hypothesis, it would appear that it is not the mode of attentional control (endogenous vs. exogenous) or the mode of cue presentation (auditory vs. visual) that is critical in modulating object-based attention in the double-rectangle task but, rather, whether the rectangle objects are encompassed within the spread of attention prior to and during attentional orienting.

General Discussion

Summary and Overall Analyses

In a series of six experiments, the present study demonstrated the critical role played by focus of attention in modulating object-based attention under endogenous and exogenous cuing. Experiment 1 reproduced the basic result obtained by Macquistan (1997) and others: a significant object-based effect under peripheral–exogenous cuing (Experiment 1A) but not under central–endogenous cuing (Experiment 1B). The remaining experiments disentangled initial spatial focus from type of orienting. Experiments 2–4 examined whether object-based attention could be elicited under endogenous cuing by allowing (Experiment 2: auditory cues), instructing (Experiment 3: central cues), or inducing (Experiment 4: both central and peripheral cues, mixed within blocks) the participants to spread their attention widely across the display while waiting for and then processing the endogenous cue. As predicted, in contrast to Experiment 1B, each of these experiments yielded significant object-based effects. Experiments 5 and 6 then took the opposite approach, attempting to prevent object-based attention by inducing an initially narrow spatial focus under peripheral–exogenous cuing (Experiment 5) and under auditory–endogenous cuing (Experiment 6), with a centrally presented go/no-go cue. As predicted, object-based effects were eliminated for orienting cues that otherwise (Experiments 1A, 2B, and 5B) yielded such effects.

Although the results of each experiment in isolation are perhaps susceptible to alternative explanations, the most parsimonious explanation of the overall pattern of results is the one that drove the experiments: Object-based effects are obtained when attention has been spread spatially over the relevant objects prior to and during the processing of the orienting cue, but not when it has been narrowly focused on the orienting cue or other central (e.g., go/no-go) cue, thereby excluding the objects and weakening their perceptual representations.

Nevertheless, before closing our treatment of the findings per se, we still must address the statistical issue that arose with regard to the reliability of the interexperiment (between-groups) comparisons. Recall that although Experiments 1A and 1B replicated the typical finding—that peripheral–exogenous cuing yields a significant object-based effect, whereas central–endogenous cuing does not—it was not possible to verify this difference statistically: Not only was there a substantial difference in the variance of the effects in the two conditions (making comparison of the means problematic), but also, given the large interindividual differences in Experiment 1B (standard central-arrow cue) and the sample sizes involved, neither a parametric nor a nonparametric comparison could be expected to reach significance. The same problem held for comparing the results of Experiment 1B with those of the various other experiments in which significant object-based effects with endogenous cues were predicted and observed (Experiments

2–4) and comparing the results of Experiments 5A and 6 (in which object-based effects were not predicted and not observed) to those of Experiments 2 and 5B (in which object-based effects were predicted and observed). Thus, we find ourselves in the awkward position of having obtained a perfect qualitative fit between the predictions of the attentional-focusing hypothesis and the statistical significance or nonsignificance of the object-based effect in each experiment while at the same time being hard put statistically to support the claim that the size of the object-based effect in fact differed between specific experiments (cuing conditions).

We believe that a satisfactory solution to this problem is provided by the results of several statistical analyses that were conducted across the six experiments (10 different cuing conditions). First, as mentioned earlier, we subjected the overall qualitative pattern of results to statistical analyses on the basis of the extent to which significant object-based effects were observed when they were expected to be observed (as predicted by the attentional-focusing hypothesis) and not observed otherwise. Across the six experiments, 10 such predictions were made, 7 predicting a significant same-object latency advantage (when initially spread attention was presumed) and 3 predicting no significant difference (when initially focused attention was presumed). All 10 predictions were confirmed. By a binomial test, the probability of obtaining such an outcome by chance (10 out of 10 successful predictions with a chance success rate of 0.5) is extremely low and highly significant ($p = .001$).[6]

Second, we conducted an overall analysis (t test) comparing the size of the object-based effect obtained in the seven cuing conditions in which such an effect was expected (in which initially spread attention was presumed; $n = 117$ participants) to the size of the effect in the three conditions in which no such effect was expected (in which initially focused attention was presumed; $n = 55$ participants). By this analysis, the same-object advantage was indeed significantly larger when attention was presumed to be spread ($M = 19.8$ ms, $SD = 36$ ms) than when it was presumed to be focused ($M = 0.5$ ms, $SD = 63$ ms), $t(170) = 2.54$, $p = .01$. Of course, despite the increased power, the latter mean did not differ significantly from zero, $t(54) = 0.06$, *ns.* However, because once again the variance of the object-based effect also differed between the two groups ($p < .05$ by Levene's test), a t test comparing groups with unequal variances was also performed, yielding essentially the same result, $t(71.3) = 2.11$, $p = .04$. A nonparametric Mann–Whitney U test yielded $z = 2.15$, $p = .03$.

In summary, overall analyses of both qualitative and quantitative results across the various experiments indicate a statistically reliable difference in both the existence and size of object-based effects between conditions that are presumed to invoke initially spread attention and those that are presumed to invoke focused attention. The issue of why the variance in the size of the object effect was generally (but not always) larger under focused-attention conditions than under diffuse-attention conditions is addressed in a later section.

We now turn to address the implications of the findings. In the following section, we focus on the implications regarding the relationship between mode of selection (object-based vs. space-based) and mode of orienting (exogenous vs. endogenous). We then discuss the necessity and sufficiency of an initially diffuse attentional setting for observing object-based effects in the spatial cuing paradigm, consider the possible role of chance or interindividual variability in attentional focusing, and, finally, present a more general framework for understanding the manner in which attentional focus, perceptual organization, and related variables modulate object-based attention.

Object-Based Attention and Mode of Attentional Orienting

It is widely agreed that there are at least two distinct (perhaps interacting) modes of attentional control: *endogenous*, in which attention is voluntarily deployed in a goal-directed manner, and *exogenous*, in which attention is involuntarily drawn to (captured by) a particular stimulus or its location in an automatic, stimulus-driven manner (Posner, 1980; for a recent review, see Yantis, 2000). A substantial amount of evidence for the existence of these two attentional modes or systems (Posner, 1980) has come from work using the spatial cuing paradigm, based on the different patterns of results obtained with endogenous (central) and exogenous (peripheral) spatial cues: Endogenous cues, typically a line or arrow pointing to (but not adjacent to) the cued location, guide attention only if the cue is generally predictive of the target location and are most effective at relatively long cue–target SOAs (300 ms or more). In contrast, exogenous cues, typically an abrupt stimulus onset or luminance change at or adjacent to the cued location, draw attention even if they are not predictive of target location, but only at short SOAs (up to 150 ms; Jonides, 1981; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989). At longer SOAs (longer than 200 ms), exogenous cues yield inhibition of return (Maylor, 1985; Posner & Cohen, 1984), whereas endogenous cues do not. In terms of processing, the effect of exogenous cuing on performance is larger for tasks that require feature integration than for those that do not (Briand & Klein, 1987), whereas there is no such difference for endogenous cuing. In contrast, manipulations of stimulus likelihood combine additively with the effects of exogenous cuing but interact with cuing when endogenous cues are used (Klein, 1994; Klein & Hansen, 1990). These differences suggest that endogenous and exogenous cues may engage not only different attentional orienting systems, but also different attentional processes (see Klein & Shore, 2000).

In view of the above, it would be most informative to discover

[6] More conservatively, one might contend that somehow we had knowledge that there was a .7 chance of obtaining a significant result across the sampled conditions, and hence, used a biased "coin" with .7 probability of landing "significant" to make our predictions. If so, the chance rate of successful prediction would be .58 (.49 chance of correctly predicting "significant" + .09 chance of correctly predicting "non-significant"), in which case the chance probability of achieving 10 out of 10 correct predictions would still be exceedingly low, $p = .004$. Taking an even more conservative posture, one might even assume that before making our predictions, we had knowledge that ten experiments would be carried out, and that the object-based effect would be non-significant in exactly three of them. By combinatorial mathematics, there are 120 different ways that three non-significant results might be distributed among ten experiments. Thus, the chance probability of choosing the "right" three experiments to predict a non-significant result is $p = 1/120 = .008$. All three calculations, then, yield very similar results, though we believe that the most appropriate calculation is the initial binomial test, which does not assume prior knowledge of the proportion of significant and non-significant results, nor of the number of experiments that would ultimately be carried out.

another basic difference between the two modes of attentional control: that exogenous orienting is inherently tied to object-based selection, whereas endogenous orienting is not. For instance, drawing on Klein's (1994; Briand & Klein, 1987) proposal regarding the unique role of exogenously controlled attention in object-feature integration, Macquistan (1997) explained his finding of an object-based effect with exogenous but not endogenous cuing as follows:

> The object-based effect in [exogenous] spatial cueing can be explained if exogenous spatial cues result in a general priming of object files so that the information from that file can be more easily accessed. Exogenous cues would affect the setting up of an object file, the accumulation of information in that file, or the accessing of information from that object file, while endogenous cues would affect earlier and later stages of processing. (p. 515)

How do the present findings bear on such a view? First, the finding of consistent object-based effects with endogenous cues across Experiments 2–4 clearly discredits the idea that endogenous orienting is inherently space-based (see also Abrams & Law, 2000): When an initially diffuse attentional setting is induced—in various ways—under endogenous cuing, robust object-based effects emerge. Thus, rather than reflecting an inherent characteristic of endogenous orienting, the common finding of space-based attention under endogenous cuing would appear to stem from arbitrary focusing tendencies induced by the physical characteristics of the typical endogenous cue (i.e., a small central arrow).

Second, the results of Experiment 5 raise serious doubts about the postulated intrinsic connection between exogenous orienting and object-based attention. Instead, this seeming connection could be due entirely to the typical task structure of peripheral–exogenous cuing tasks, which almost inevitably encourage an initially diffuse attentional setting. Unlike the typical central–endogenous cuing task, which generally entails a structured tension between the desire to attend to the potential target locations (i.e., the ends of the rectangles) and the need to process the centrally presented arrow, the peripheral–exogenous cuing task entails no such tension. On the contrary, under pure exogenous cuing, spreading one's attention across the rectangles is the natural strategy, and also under predictive peripheral cuing (typical of most studies using the double-rectangle paradigm), spread attention should be beneficial in increasing the attention-capturing power of the cue (Theeuwes, 1991). Indeed, when such a tension was artificially introduced in Experiment 5A, by requiring participants to attend to a central go/no-go cue before the appearance of the peripheral–exogenous orienting cue, the object-based effect was completely eliminated. Notably, a similar result was obtained in Experiment 6, in which the need for focused attention to the central go/no-go cue eradicated the object-based effect under endogenous auditory-tone cuing that earlier (Experiment 2B) had presumably allowed participants to process the displays under a diffuse attentional setting.

In summary, when interpreted in light of the attentional-focusing hypothesis, the overall pattern of results in the present study suggests that the different tendencies of endogenous and exogenous cues to yield object-based effects can be explained entirely by differences in the initial distributions of attention in the two conditions, without recourse to a postulated interdependency between mode of orienting and object-based versus space-based attention.

Modulation of Object-Based Attention by Attentional Focus in the Spatial-Cuing Paradigm

The present results indicate that the initial spatial focus of attention is a critical factor modulating object-based attention in the double-rectangle spatial cuing paradigm: Attentional deployment in response to the orienting cue—endogenous or exogenous—may be either object-based or space-based, depending on whether attention is widely spread or narrowly focused when the orienting takes place. Several issues concerning the nature of that dependency, however, require clarification. First, is encompassing the relevant objects under widely spread attention a sufficient condition for object-based effects to emerge under spatial cuing? The fact that object-based effects were consistently obtained under conditions in which the rectangle objects had no functional value or role might suggest that given a diffuse attentional setting, object-based attention is obligatory (cf. Goldsmith, 1998; Kahneman & Henik, 1981). Conceivably, however, even though attention is appropriately spread, object-based selection or navigation might still be overridden, either by strategic factors (e.g., when such selection is detrimental to performance; Beck & Palmer, 2002; Cepeda & Kramer, 1999; Shomstein & Yantis, 2000) or by perceptual factors (e.g., when the object quality is poor; Avrahami, 1999; Kramer & Watson, 1996; Watson & Kramer, 1999). More work is needed on this issue. At present, the results suggest that object-based attention may be the default attentional mode, given a spatially diffuse attentional setting.

A second issue concerns whether encompassing the objects within a spatially diffuse attentional setting is a necessary condition for object-based attention under spatial cuing. This issue emerges, in particular, with regard to the Abrams and Law (2000) study mentioned earlier. These researchers found object-based effects with central arrow cues (which presumably invoked focused attention to the cue) in six experiments, four of which were variations on the double-rectangle task. Does the Abrams and Law (2000) study constitute a counterexample to the attentional-focusing hypothesis?

Abrams and Law (2000) noted several differences between the experimental conditions in their study and those in earlier studies (e.g., Macquistan, 1997) that had failed to find object-based effects with central arrow cues. Several of these were examined experimentally: cue–target SOA variability (Experiment 5), control of eye movements (Experiment 6), and whether or not the procedure included the presentation of far-location different-object targets on invalid-cue trials (Experiment 7). None of these factors appeared to account for the inconsistent results. Let us, then, consider whether there were other factors that may have led participants to adopt a more diffuse attentional setting in the Abrams and Law (2000) study or that might have interacted with the effects of attentional focus, inducing object-based attention despite an initially constricted attentional setting.

Two of Abrams and Law's (2000) endogenous cuing experiments did not involve the double-rectangle paradigm. One of these (Experiment 3) was a spatially distributed divided-attention task, in which participants judged which of two dots appeared first on the display (the two dots could be located either within the same object or in different objects). Arguably, such a task should encourage the strategic adoption of a diffuse attentional setting, which could then account for the observed object-based effect (cf. the present Experiment 4). In the second experiment (Experiment 4), the participants' task was to judge a feature of the object itself (the size of a gap in its contour; see also Law & Abrams, 2002). Here too, participants may have set a relatively wide attentional aperture that would allow them to perceive the gap size within the context of the global object (trapezoid) shape. Alternatively, it may be that object-based effects in tasks pertaining to the features of single, uniformly connected objects (Watson & Kramer, 1999) are less sensitive to the initial focus of attention than are object-based effects in the double-rectangle paradigm, which involves detection or feature discriminations pertaining to a perceptually distinct target object (e.g., a square or triangle) rather than to the rectangle object per se (cf. Lamy & Egeth, 2002; and see further discussion below).

Turning now to the four experiments that used the double-rectangle paradigm (Abrams & Law, 2000, Experiments 2, 5, 6, and 7), all of these involved a simple detection task, whereas Macquistan (1997) and the present study involved discrimination tasks. Assuming that their detection task was less perceptually demanding than our discrimination task (and perhaps other detection tasks; e.g., Arrington, Dagenbach, et al., 2000; Dagenbach et al., 1997), a more widely spread distribution of attention would be expected (Downing, 1988; Handy, Kingstone, & Mangun, 1996). Conceivably, the focus or spread of attention might also be influenced by differences in the ease or difficulty of processing the central arrow cue (differences in size, discriminability, etc.), as well as by differences in the perceptual salience of the rectangle objects.[7] Differences in the perceptual salience of the objects would be expected to lead to differences in the robustness of their representations and in the dependence of these representations on attentional focus (e.g., Goldsmith, 1998; Most et al., 2001; Treisman & Sato, 1990; Wolfe, 1994). It should be worth examining whether such stimulus–task differences do in fact modulate the distribution of attention and/or the robustness of the rectangle-object representations and, hence, the object-based effects that are observed.

Finally, a third issue, which cuts across the necessity–sufficiency issues, concerns inter- and intraindividual variability in spatial focusing. In general, not only systematic stimulus–task variables but also random fluctuations or individual differences in attentional breadth (Pringle, Irwin, Kramer, & Atchley, 2001) are more likely to influence the focus of attention under central–endogenous cuing than under peripheral–exogenous cuing, the latter calling strongly and unambiguously for an initially spread attentional setting. Hence, greater variability in results regarding object-based attention should be expected under central cuing, both within and between experiments.

Several results in the present study suggest a contributing role for variability in spatial focusing. First, such differences could account for the relatively large variance in the size of the same-object–different-object latency difference (RT_{diff}) observed in the present study in the standard central-arrow cue condition (Experiment 1B) compared with that observed under peripheral–exogenous cuing (Experiment 1A) or under conditions in which instructions (Experiment 3) or expedience (Experiment 4) were likely to induce a more consistent (diffuse) focusing strategy. Second, the increased variance in RT_{diff} when the central go/no-go cue was added to the peripheral–exogenous orienting task (Experiment 5A), compared with that observed in the peripheral–exogenous control condition (Experiment 5B) and the standard peripheral–exogenous cuing condition (Experiment 1A), may be due in part to the tension that was introduced between the need to focus on the central go/no-go cue and the need to detect a peripherally presented target.

A more subtle effect of focusing variability may also underlie the large variances observed in the auditory cuing conditions (Experiments 2A, 2B, and 6). In those conditions, the relatively long cue–target SOAs needed for effective auditory cuing (1300 ms in Experiment 2A; 800 ms in Experiments 2B and 6) may have provided some of the participants with enough time to zoom in spatially on the cued location after processing the orienting cue (in Experiments 2A and 2B) or to spatially zoom out after processing the central go/no-go cue (in Experiment 6). In line with this idea, note that Experiment 6, which combined both of the factors just considered—a task structure that encouraged participants to change their spatial attentional aperture from initially focused to spread, together with a relatively long cue–target SOA in which to do so—also yielded the largest amount of interindividual variability in RT_{diff} ($SD = 91$ ms).

Clearly, many of the ideas put forward in this section are speculative, and more work is needed. Nevertheless, the discussion can serve to illustrate some of the complexities that arise under the attentional-focusing hypothesis and to highlight the need for a more general theoretical model that delineates the antecedents and consequences of attentional focus, as well as potential interactions with other variables.

Toward a More General Theoretical Framework

Proposed Perceptual-Organization Conception

Examination of the recent literature yields a variety of proposed moderators of object-based attention: (a) mode of cuing and attentional orienting, exogenous versus endogenous (Arrington, Dagenbach, et al., 2000; Dagenbach et al., 1997; Macquistan, 1997; Neely & Dagenbach, 1996); (b) attentional focus (Atchley & Kramer, 2001; Lavie & Driver, 1996); (c) availability and quality of the object representation (Avrahami, 1999; Baylis & Driver, 1995; Driver & Baylis, 1995; Ho & Atchley, 2001; Kramer & Watson, 1996; Watson & Kramer, 1999); (d) need for an attentional shift or serial attentional scan (Lamy & Egeth, 2002; Shomstein & Yantis, 2002); (e) top-down influences and strategic control (Cepeda & Kramer, 1999; Shomstein & Yantis, 2000; Watson & Kramer, 1999; Zemel, Behrmann, Mozer, & Bavelier, 2002); and (f) the nature of the task (e.g., detection vs. shape discrimination; Brawn & Snowden, 2000; Vecera & Farah, 1994). These

[7] One of the factors affecting object salience is the stroke (width) of the contour lines. Abrams & Law (2000) did not report the stroke of the rectangle contour lines in the four endogenous-cuing experiments (Experiments 2, 5, 6, and 7; all of which used the same stimuli). In Experiment 1 of their study, however, which used peripheral cuing, the stroke of the rectangles was reported as 0.4°, which is almost three times greater than the one used in the present study (0.15°) and twice the stroke used in Egly, Driver, and Rafal's (1994) original study (0.2°).

variables have often been examined in isolation, yielding a fragmented and seemingly inconsistent picture.

The present study attempted to provide a partial integration of the operation of the first two variables, mode of cuing (orienting) and attentional focus. In doing so, several of the other variables were also implicated, in particular the availability and quality of the object representation and strategic control. In fact, the general proposal that guided the present study might be cast as follows:

1. The object-based deployment of attention requires a viable perceptual representation of the relevant objects in the current perceptual organization of the scene or display.

2. This, in turn, requires that the objects be encompassed within the spatial spread of attention, either just prior to or during the attentional deployment.

3. The focus or spread of attention depends on (a) bottom-up influences and constraints deriving from task–stimulus structure and (b) top-down strategic control.

The attentional-focusing hypothesis put forward in this article must be understood and evaluated within the context of this more general framework, which posits that the contribution of attentional focusing to object-based attention is mediated by its role in perceptual organization (i.e., the formation, maintenance, and dissolution of object representations). This conception of the hypothesis is quite different from interpretations that posit a direct, intrinsic conflict between the space-based and object-based modes of selection (cf. Atchley & Kramer, 2001; Law & Abrams, 2002). Unlike under the "direct-conflict" interpretation, to derive predictions under the perceptual-organization version of the hypothesis, one must consider the detailed temporal and spatial dynamics of attentional focusing during the course of an experimental trial or scanning episode and, in particular, how those dynamics affect the quality of the object representations that exist at the time of attentional orienting. Ultimately, it is the quality of the object representation at the time of deployment that determines the type of selection (object-based or space-based) that is invoked by that deployment. Moreover, one cannot assume that the attentional dynamics (and resulting perceptual representations) are identical under all conditions or for all individuals: Both top-down (strategic) and bottom-up (stimulus) factors can affect the manner in which attention is maneuvered, from the initial fixation at the beginning of a trial until the final fixation on the target object or location (Benso, Turatto, Mascetti, & Umiltá, 1998; Turatto et al., 2000).

Comparison With the Original Hypothesis: Lavie and Driver (1996)

To clarify the perceptual-organization conception and illustrate some of its unique implications, first consider the original version of the attentional-focusing hypothesis, as proposed by Lavie and Driver (1996). In their study, Lavie and Driver examined (and ultimately rejected) the idea that object-based attention might be limited to very compact stimulus displays in which the relevant stimuli are too small to be selected effectively by a spatial attentional spotlight (cf. B. A. Eriksen & Eriksen, 1974). With a relatively large display (13° in breadth), they found that same–different responses in a speeded matching task were faster when the targets to be compared (e.g., dash or dot) appeared on the same object (one of two intersecting lines) than when they appeared on different objects (in Experiments 1–3). Thus, they concluded that object-based effects are not limited to small displays.

Their more important finding, however, came—almost incidentally—from a final experiment involving spatial cuing. Because the targets to be compared in their experiments were equally likely to be located at either end of the display (and could also be located at both ends), Lavie and Driver (1996) assumed that the participants were setting a spatially diffuse attentional aperture in anticipation of the target–display onset (the lines and embedded targets were presented simultaneously). To determine whether such a setting was critical for the object-based effect to occur (Experiment 4), they induced focused attention to one side of the display by presenting a peripheral precue (70% validity) shortly before target–display onset. In this case, the same-object advantage disappeared. Lavie and Driver (1996) concluded that "object-based selection may only operate within spatially attended regions" (p. 1238), though the extent of the attended region may be either wide or narrow. Note that the reason for this modulation was not explicitly specified.

Subsequent examinations of Lavie and Driver's (1996) results have raised doubts about both the reliability and the general applicability of the attentional-focusing hypothesis. First, Lavie and Driver's results have not been easy to replicate (Lamy, 2000), though it appears that replication is possible under certain conditions (Atchley & Kramer, 2001; Law & Abrams, 2002). Second, and even more troubling, Lavie and Driver's findings are generally perceived to conflict with the large number of studies finding object-based effects in the double-rectangle paradigm (under peripheral cuing). For example, in a recent article on the modulation of object-based attention, Lamy and Egeth (2002; see also Law & Abrams, 2002) pointed to this conflict (as well as to the replication difficulties) as grounds for dismissing the idea that object-based attention depends on the spatial extent of attention; in their words,

> Lavie and Driver [1996] concluded that object-based effects may be found when attention is distributed in a diffuse mode across the display, but not when it is focused on a narrow spatial area within this display. This conclusion may apply only under specific circumstances yet to be defined, because there have been numerous reports of object-based effects with attention focused on a small part of the display [Egly, Driver, & Rafal, 1994, among others]. . . . So, at least on the basis of existing evidence, the spatial extent of attention does not seem to be a critical factor for defining the boundary conditions between space-based and object-based selection. (p. 53)

There are several differences between the task used by Lavie and Driver (1996) and the one used here (e.g., Experiment 1A) and elsewhere (e.g., Egly, Driver, & Rafal, 1994) that could explain the conflicting results, including the use of a spatially distributed matching task rather than a simple detection or discrimination task (Lamy & Egeth, 2002), spatial cuing that does not cue a specific object (Atchley & Kramer, 2001; Law & Abrams, 2002), and different relative timings of the cue, object, and target onsets and offsets (Ho & Atchley, 2001; Law & Abrams, 2002; Neely, Dagenbach, Thompson, & Carr, 1998).

However, it is not just the conflicting results but the conflicting predictions of the attentional-focusing hypothesis in the two experimental tasks that must be reconciled: Why, in Lavie and Driver's (1996) study, was the elimination of object-based effects by peripheral spatial cuing taken to support the proposition that widely spread attention is crucial for object-based attention, whereas in the present study, the robust existence of object-based effects under peripheral spatial cuing (as opposed to the general absence of such effects under central cuing) is treated as supporting that same proposition?

We propose that both the conflicting predictions and the conflicting results between the Lavie and Driver (1996) task and the typical double-rectangle task can be reconciled by considering the temporal differences in the two tasks, which become crucial under the perceptual-organization conception of the attentional-focusing hypothesis. In Lavie and Driver's (1996, Experiment 4) task, the peripheral cue was presented 70 ms before the appearance of the line objects and embedded targets (that is, cue–object SOA = cue–target SOA = 70 ms). Hence, if attention was captured and focused quickly enough by the abrupt onset of the peripheral cue, this could have prevented the formation of object representations capable of supporting object-based attention. In contrast, the peripheral cues in the double-rectangle paradigm are typically presented long after the onset of the rectangle objects (cue–object SOA = −1,000 ms in the present Experiment 1A) but shortly before the onset of the target (cue–target SOA = 100 ms in the present Experiment 1A). In this case, there is clearly ample time to form the needed object representations under spread attention, and the 100-ms cue–target SOA is presumably not long enough for those representations to dissolve or decay as a result of focusing attention elsewhere (this should be particularly true when part of the object itself constitutes the cue, as in Egly, Driver, & Rafal, 1994).

Consistent with this idea, Ho and Atchley (2001) found object-based effects in a simple detection task with overlapping line objects when the peripheral cue was presented either 75 ms or 150 ms after the line objects but not when the cue was presented simultaneously with or 75 ms before the line objects. It is interesting to note, however, that object-based effects were obtained when the cue preceded the line objects by an even longer interval (150 ms). This may have occurred because 150 ms is greater than the typical capture period of abrupt-onset cues (Müller & Rabbitt, 1989), allowing participants to begin spreading their attention out again before the line objects appeared (for similar results, see Neely et al., 1998).

Relatedly, Law and Abrams (2002) recently found that the results obtained with the Lavie and Driver (1996) task are highly dependent on the exposure duration of the relevant objects: Although Lavie and Driver's (1996, Experiment 4; no object-based effect) result was replicated when the same stimulus duration (129 ms) was used for presenting the crossed lines, increasing the exposure duration slightly (to 186 ms) was sufficient to yield the opposite result. In explaining this difference, Law and Abrams (2002), as do we, suggested that the critical factor determining whether or not attention is object based is the availability or unavailability of a perceptual object representation:

> We believe that the shorter [object exposure] duration either did not permit establishment of object representations or did not allow enough time for object representations to be established prior to the availability of the information needed to perform the task through some alternate representation. (p. 1026)

However, because in their study Law and Abrams (2002) implicitly spoke to the direct-conflict interpretation of the attentional-focusing hypothesis—that is, the idea that focused spatial attention somehow interferes with "simultaneous" object-based attention—the conclusion that they ultimately drew from their results was to reject the hypothesis; in their words,

> spatially directed attention and object-based attention can exist simultaneously: Object-based selection was observed in the absence of focused spatial attention, as well as in the presence of focused attention as directed by three different types of cues. . . . The focusing of attention did not reduce the object advantage measurably. (p. 1026)

In contrast, from the perspective of the perceptual-organization version of the attentional-focusing hypothesis, put forward here, Law and Abrams' (2002) results again illustrate the need to consider the effect that focusing attention at one point in time might have on the subsequent availability or unavailability of a viable perceptual-object representation—at the time of selection. After spatial attention was narrowed in response to the spatial cue, given the fact that in the critical experimental conditions (far–same object and far–different object), the features to be matched were widely distributed spatially (on opposite sides of the display; cf. Abrams & Law, 2000, Experiment 3), and that they were in fact features of the objects themselves (i.e., gaps in the lines; cf. Abrams & Law, 2000, Experiment 4), the increased object exposure times may very well have enabled the participants to build viable object representations on the fly as they spread their attention out again to detect (discriminate) the location (size) of the gap in the line at the far (uncued) side of the display.

In summary, when examined from a dynamic, interactive, perceptual-organization perspective, the predictions and findings of Lavie and Driver (1996), Egly, Driver, and Rafal (1994), Law and Abrams (2002), and the present study are actually quite consistent, both among themselves and with the attentional-focusing hypothesis. It is unfortunate that the direct-conflict interpretation of the hypothesis, which does not take the potentially complex temporal and spatial dynamics of attention (and perceptual organization) into account, has diminished the hypothesis' potential appeal, yielding seeming inconsistencies when applied indiscriminately to experimental findings.

Implications for Other Proposed Moderators

We now consider several other proposed moderators of object-based attention from the perspective of the more general attentional-focusing framework.

Stimulus-Object Quality

As discussed earlier, stimulus factors might also be expected to interact with the effects of attentional focus on perceptual organization and, hence, lead to different patterns of object-based effects across experiments. For example, in attempting to reconcile Abrams and Law's (2000) results with the attentional-focusing hypothesis, we speculated that differences in stimulus salience may make some object representations—and hence, object-based attention—more dependent on the spatial spread of attention than others. In general, some object representations may be more dependent on attention for their creation or maintenance (e.g., Goldsmith, 1998; Mack & Rock, 1998; Treisman, 1988; Treisman & Sato, 1990; Wolfe, 1994), or have different time courses for their microgenesis (e.g., Kimchi, 2000; Palmer & Rock, 1994). Consequently, perhaps some stimulus objects will yield more robust object-based effects than others.

Consistent with this idea, Watson and Kramer (1999), who examined "the nature of the object representations from which attention can select" (p. 32; see also Avrahami, 1999; Baylis & Driver, 1995; Driver & Baylis, 1995; Driver et al., 2001), identified uniform connectedness (Palmer & Rock, 1994) as a critical property modulating object-based effects. They found that although attention could, under some conditions (e.g., when induced by top-down strategic factors or priming), be directed to *grouped-UC* representations (i.e., objects composed of groups of uniformly connected regions) or to *parsed-UC* representations (i.e., segmented uniformly connected regions), by far the most natural and robust object selection took place from *single-UC* representations (i.e., objects composed of a single uniformly connected region). If single-UC object representations typically place relatively low demands on attention for their creation and maintenance (Palmer & Rock, 1994), then part of the superior object-based selection with such objects may stem from lessened sensitivity to the focus of attention.

A question that must still be answered, then, is whether the same pattern of results regarding focus of attention found in the present study using the double-rectangle paradigm (in which object-based attention generally relates to grouped-UC objects, i.e., a rectangle and accompanying target object) will hold for tasks that involve more unitary single-UC objects (cf. Lamy & Egeth, 2002). In particular, will object-based effects in tasks with single-UC objects and their features (e.g., detecting whether a wrench is bent or has an open end) be sensitive to attentional focus? The influences of object size, complexity, salience, and realism (cf. Atchley & Kramer, 2001; Avrahami, 1999; Moore et al., 1998; Saiki, 2000; Vecera, Behrmann, & McGoldrick, 2000) will also need to be examined.

Strategic Control

A question has been raised concerning the extent to which object-based attention is or is not under strategic control (e.g., Cepeda & Kramer, 1999; Shomstein & Yantis, 2000). For example, Shomstein and Yantis (2000) found that object-based attention in the double-rectangle task can be modulated by manipulating the relative probabilities of the same-object and different-object target locations on invalid-cue trials: When invalidly cued targets were made much more likely to appear in the uncued rectangle, the same-object RT advantage was eliminated (cf. Kunde & Hoffmann, 2002).

Strategic control over the spatial distribution of attention prior to the selection of objects or locations may constitute one of the mechanisms by which object-based attention is modulated. For example, if participants were motivated to avoid giving priority to the same-object invalid-cue location in the double-rectangle paradigm, the present results suggest an efficient strategy for doing so: maintaining a narrow focus of attention on the center of the screen while processing the cue until just prior to the attentional orienting. Conversely, one could enhance object-based processing (under central–endogenous cuing) by attempting to maintain a widely spread attentional setting prior to orienting. Future research will need to examine the extent to which strategic control of attentional focusing is used to regulate object-based versus space-based selection.

Attention Switching and Scan-Order Prioritizing

Two other recent proposals concerning the moderators and boundary conditions of object-based attention are relevant to the attentional-focusing hypothesis and to the present work. First, Shomstein and Yantis (2002) also reported the attenuation of object-based effects under conditions in which attention was narrowly focused in advance. In a clever adaptation of the classic flanker-interference paradigm, they presented a target letter and two flanking distractors on rectangular slabs configured in a cross shape, with the distractors located either on the same slab as the target (same-object condition) or on two adjacent slabs (different-object condition). When attention could be narrowly focused in advance on the target location (i.e., on the center of the cross configuration; Experiments 1–4), the interference from same-object distractors was no greater than the interference from different-object distractors. In contrast, when participants had to scan the cross configuration to locate the target (Experiment 5), object-based interference was observed. On the basis of this pattern of results, Shomstein and Yantis concluded that object-based effects occur only in tasks that require the scanning of multiple locations, in which case the same-object advantage (or disadvantage) is due to attentional scan-order prioritizing: Participants tend to scan locations within the same object first, before moving on to locations in a different object.

A similar idea was put forward by Lamy and Egeth (2002), who proposed that object-based effects involving grouped-UC objects (Watson & Kramer, 1999), such as those in the double-rectangle task, are observed only in tasks that require an attentional shift between different locations—the shift being easier to perform within the same object than between different objects. For example, in two of Lamy and Egeth's experiments that are most pertinent to the present article, a significant same-object advantage was found with peripheral cuing in a standard double-rectangle size-discrimination task (Experiment 2), but using the same task within an interference paradigm, in which the target location was precued with 100% validity (Experiment 4), eliminated the object-based effect: The amount of interference from same-object distractors was no greater than the interference from (equally distant) different-object distractors, presumably because neither within-object nor between-object attentional shifts were required once attention had been oriented to the cued location. These results are similar to the findings of Shomstein and Yantis (2002) mentioned above, though Lamy and Egeth argued that the same-object advantage, when present, derives from a between-object attention-switching cost on invalidly cued different-object trials rather than a same-object bias in the scanning order on all invalidly cued trials.

Both Shomstein and Yantis's (2002) and Lamy and Egeth's (2002) results may perhaps involve the modulation of object-based attention by spatial focusing. With regard to Shomstein and Yantis (2002), not only is the absence of object-based interference when attention is narrowly prefocused on the target location (Experiments 1–4) compatible with the attentional-focusing hypothesis, but the hypothesis also offers an alternative explanation for the presence of object-based effects in that study (Experiment 5): Uncertainty about the location of the target within the slab configuration would be expected to elicit object-based attention (interference) by inducing participants to spread their attention widely over the entire slab configuration while waiting for the letter stimuli to appear, thereby creating and maintaining viable slab-object representations.

Turning to Lamy and Egeth's (2002) results, in their Experiment 4, no object-based interference was observed when the target location was precued with 100% validity. Why so? One possibility is that part of the dependency of object-based attention on attentional spread involves the spread of attention during and after (not just before) attentional orienting. When endogenous or exogenous cues are less than 100% valid across trials, arguably participants should try not to focus too narrowly on the cued location, keeping an eye out to detect the location of an invalidly cued target should one appear. This could be achieved by setting up a broad gradient of attention (Downing & Pinker, 1985) in which the cued location receives the largest allocation, and attentional resources decrease as they spread out toward the other possible locations. In fact, the gradient itself might be object-based such that its shape and topography are distorted in accordance with object boundaries and other grouping factors.[8] Clearly, there would be no reason to set up such a gradient when the target location is signaled with 100% certainty. Of course, it may also be that although spread attention is (usually) needed for the creation and maintenance of object representations that can support object-based attention, object-based effects are only expressed in the shift of attention from one location to another. This latter possibility relates to the issue, discussed earlier, of whether object-based attention is obligatory given a widely spread attentional setting.

Concluding Remarks

The claim that object-based attention is dependent on the spatial spread of attention may seem paradoxical, given that the term *object-based attention* (in the grouped-array sense) denotes that the spatial spread of attention is influenced by object boundaries and groupings. The claim makes sense, however, within a dynamic and interactive processing framework (e.g., Driver et al., 2001; Grossberg et al., 1994; Humphreys et al., 1996; Peterson & Gibson, 1991, 1994; Vecera & Farah, 1997) and when certain underlying assumptions are clarified. As discussed earlier, the attentional-focusing hypothesis put forward previously by Lavie and Driver (1996) appears to have suffered from an overly literal interpretation that does not specify the mechanism by which attentional focus modulates object-based attention. We hope that our present explication of such a mechanism, combined with a convincing demonstration of the modulation of object-based attention by attentional focus, will help revitalize the hypothesis, encouraging its future use and development in research and theorizing about the complex relationship between object-based and space-based attention.

[8] Both the attentional-shift and the biased-scanning-order hypotheses have been contrasted to the idea of an automatic "radiation" of attention that flows from the attended location throughout the rest of the object, respecting object borders (see Abrams & Law, 2000; Lamy & Egeth, 2002; Shomstein & Yantis, 2002). An alternative model, which has yet to be considered, involves the idea that grouped-array object-based attention operates as an endogenously adjustable attentional *gradient* (cf. Downing & Pinker, 1985) that is shallower within than between objects. The exact shape and topography of the gradient might depend not only on object boundaries and grouping, but also on strategic factors, such as the validity of the cue and the difficulty of detecting an invalidly cued target. The object-based gradient model is also consistent with the accumulating evidence against the automatic radiation account.

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