Psychonomic Bulletin & Review
2004, 11 (1), 84-91

Hemispheric performance in object-based attention

MONICA A. VALSANGKAR-SMYTH
University of Alberta, Edmonton, Alberta, Canada

CHRISTA-LYNN DONOVAN
University of British Columbia, Vancouver, British Columbia, Canada

SCOTT SINNETT
University of Barcelona, Barcelona, Spain

MICHAEL R. W. DAWSON
University of Alberta, Edmonton, Alberta, Canada

and

ALAN KINGSTONE
University of British Columbia, Vancouver, British Columbia, Canada

The goal of the present study was to investigate whether object-based attention effects differ across the cerebral hemispheres. Previous research has suggested that object-based attention is preferentially lateralized to the left hemisphere (Egly, Driver, & Rafal, 1994; Egly, Rafal, Driver, & Starrveveld, 1994). However, work by Vecera (1994) has suggested that these previous studies may have failed to obtain a pure measure of object-based attention. The present study applied modified versions of Duncan's (1984) seminal object-based attention paradigm. Subjects were typically presented with one target object to a single visual field (one-object display), two target objects to the same visual field (two-object unilateral display), or two target objects to different visual fields (two-object bilateral display). In all three experiments, response accuracy was higher for the one-object displays than for the two-object displays. Most important, this object-based cost was especially severe when selection of two target elements was isolated to the right visual field (left hemisphere). We confirmed that this effect was specific to object-based attention in three different ways: Experiment 1 manipulated stimulus distance, as recommended by Vecera; Experiment 2 ensured that target selection was based on nonspatial attributes; and Experiment 3 used overlapping displays, as in Duncan (1984). Collectively, the data are in accord with previous conclusions that object-based attention is a specialized form of orienting subserved by lateralized cortical brain mechanisms. However, contrary to previous research, it appears that it is the right hemisphere, and not the left hemisphere, that is preferentially biased for committing object-based attention to elements in the visual environment.

In 1980, Posner and colleagues suggested that selective visual attention could be likened to a mental "spotlight" that is committed to specific spatial locations (Posner, 1980; Posner, Snyder, & Davidson, 1980). Stimuli that appear within the "beam" of the attentional spotlight are "illuminated" and processed more efficiently than stimuli at unattended locations. The behavioral result is that response times (RTs) and/or response errors are reduced for stimuli at attended versus unattended positions.

This work was supported by grants to A.K. from the the Human Frontier Science Program, the Natural Sciences and Engineering Research Council of Canada, and the Michael Smith Foundation for Health Research. We thank David Balota, John Wixted, John Duncan, and an anonymous reviewer for their comments. Correspondence should be directed to A. Kingstone, 2136 West Mall, Department of Psychology, University of British Columbia, Vancouver, BC, V6T 1Z4 Canada (e-mail: alan.kingstone@ubc.ca).

A few years later, a seminal paper by Duncan (1984) reported that visual selective attention could also be committed to specific objects, as well as to specific locations. Duncan found that errors increased when subjects were required to make a single judgment about two objects, as compared with when they were required to make two judgments about a single object. Because the two objects shared the same location in space, a purely space-based theory of attention predicted that the two objects should have been processed as easily as one object. The fact that there was a cost in attending to two objects at the same location demonstrated that selection could be object based, as well as space based.

More recent evidence has suggested that different brain regions may subserve space-based and object-based attention. For instance, in a particularly influential study Egly, Driver, and Rafal (1994) measured both space-based and object-based attention in a single paradigm. Parietal lesion patients were presented with displays that consisted of two outline rectangles positioned either above and below central fixation or to the right and left of central fixation. Attention was drawn to the end of one of the rectangles by an abrupt peripheral flash (called a *cue*). Then a target requiring a detection response was presented at one of three possible locations: at the cued location, at the noncued end of the cued rectangle, or at a noncued end of the noncued rectangle. It was expected that RTs to a target at a noncued location would be longer than RTs to a target at a cued location, because of the additional time required to shift attention from the cued location to the noncued location. The question was whether a space-based attentional effect (shifting attention within the cued object [cued location vs. noncued location within the same rectangle]) would differ from an object-based attentional effect (shifting attention between the cued object and the noncued object [cued location vs. noncued location on different rectangles]). Results suggested that right-hemisphere lesion patients exhibited a space-based attention deficit and left-hemisphere lesion patients exhibited an object-based attention deficit. These results were interpreted as indicating that the left and the right cerebral hemispheres are differentially specialized for space-based (right-hemisphere) and object-based (left-hemisphere) attentional orienting.

Egly, Rafal, Driver, and Starrveveld (1994) conducted a similar experiment with a split-brain patient. The paradigm was the same as that in Egly, Driver, and Rafal's (1994) study, except that now there were always four rectangles presented to the subject, two in each visual field. When the targets were presented in the left visual field (LVF; right hemisphere), there were no significant differences in the RT cost of shifting attention within an object and between objects. When targets were presented in the right visual field (RVF; left hemisphere), however, the split-brain patient was much slower to respond when shifts of attention between objects were required than when shifts of attention within an object were required. The authors concluded that this study dovetailed with the evidence from the parietal lesion patients—that is, the right hemisphere was specialized for space-based attention, and the left hemisphere was specialized for object-based attention.

Vecera (1994), however, has questioned this interpretation of the studies of Egly and colleagues (Egly, Driver, & Rafal, 1994; Egly, Rafal, et al., 1994). Specifically, Vecera found that the object-based attention effect in these studies—shifting attention between a cued and a noncued rectangle—was extremely sensitive to changes in the distance that separated the two rectangles.

The implication of Vecera's (1994) finding should not be underestimated. If the object-based attention effects reported by Egly and colleagues (Egly, Driver, & Rafal, 1994; Egly, Rafal, et al., 1994) are sensitive to spatial manipulations, the hemispheric differences reported in Egly and colleagues' patient studies may merely reflect differences in space-based attentional orienting and have little to do with object-based attentional orienting. Thus, the question remains open as to whether the brain mechanisms subserving object-based and space-based attention are represented differentially between the cerebral hemispheres. The goal of the present study was to address this question.

EXPERIMENT 1

The task was for healthy subjects to judge whether objects in two different displays were the same or different (see Figure 1). In the target display, one or two objects were presented briefly and then masked. For two-object displays, the items could both be in the same visual field (two-object unilateral display) and, therefore, project to the same hemisphere, or the two objects could be in different visual fields (two-object bilateral display) and, therefore, project to different hemispheres. In the final display, a probe item was always presented at the location of one of the target objects. Half the time the probe matched the previous object, and half the time it differed. From previous research (e.g., Baylis & Driver, 1993; Duncan, 1984, 1993; Enns & Kingstone, 1997; Vecera & Farah, 1994), we expected that response accuracy would be reduced when the subjects were required to attend to two objects in the initial display, as compared with when they had to attend only to a single object—that is, there should be a two-object cost. The critical question was whether this object-based attention effect would be the same or different between the hemispheres. To confirm that our object-based attention effect was not an artifact of space-based attentional orienting, we applied the same test as that in Vecera (1994) and manipulated the distance between objects.

Method

Subjects. Thirty-two undergraduate psychology students were tested. All had normal or corrected-to-normal vision and received course credit for their participation.

Apparatus. This experiment was conducted on a Macintosh 66 computer. The stimuli were presented on a 14-in. Apple color monitor (set to black and white) at a viewing distance of approximately 57 cm. Responses were collected from keyboard buttonpresses.

Stimuli and Procedure. Figure 1 illustrates the sequence of stimulus events presented in a given trial. The initial display signaled the start of a trial and consisted of a black central fixation point with four black location markers on a gray background. For half of the subjects, these markers were located 4º from central fixation (*near* condition), and for the remaining half of the subjects, the markers were located 8º from fixation (*far* condition). In both the near and the far conditions, the location markers were positioned on the four corners of an imaginary square centered on fixation. The subjects were instructed to keep their eyes on the fixation point at the start of each trial and to withhold any eye movements until the end of the trial. The duration of this initial display was 700 msec. The next display (the *target display*) was composed of one or two horizontal or vertical black ovals. The ovals subtended $0.9^\circ \times 0.7^\circ$ of visual angle and were presented in the location markers for 100, 150, or 200 msec (each duration was equiprobable and randomly selected). Immediately following this display was a 180-msec display consisting of

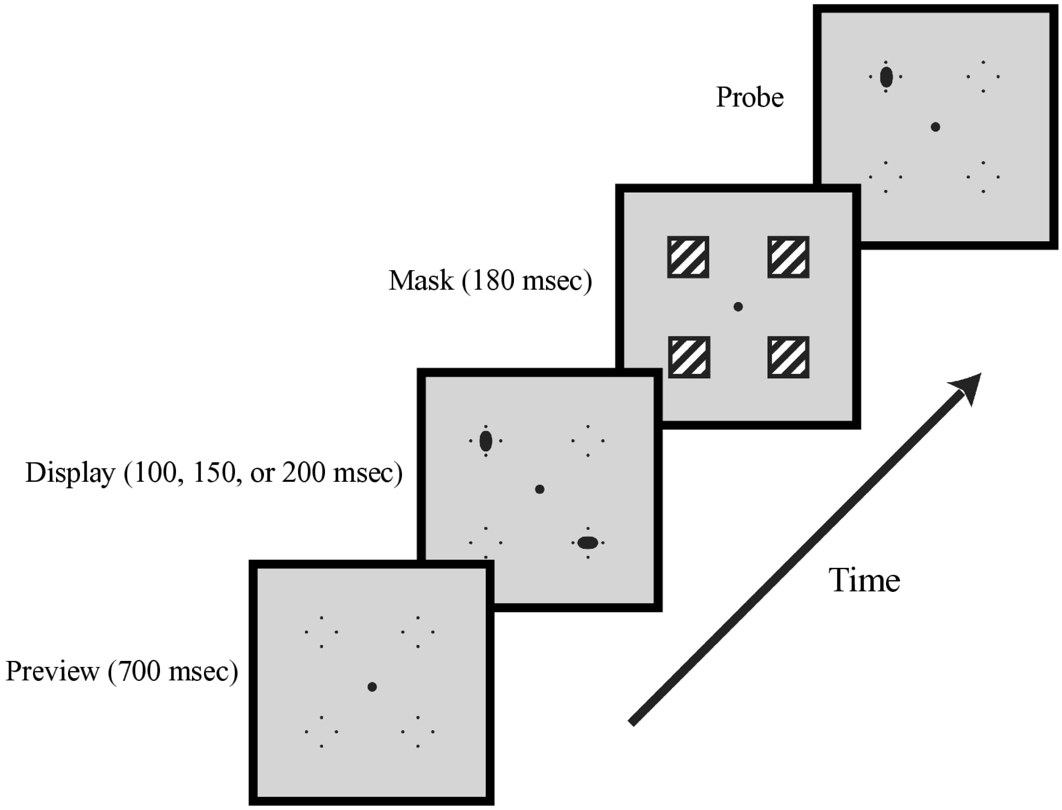

Figure 1. Example of the sequence of events in Experiment 1 on a two-object bilateral display trial. Each trial began with the presentation of a central fixation point with four location markers. After 700 msec, either one or two horizontal or vertical black ovals would appear within the location markers for 100, 150, or 200 msec (target display). A 180-msec masking display was then presented. The final (probe) display was similar to the target display, except that only one black oval was presented in the same location as a black oval in the target display. The task was to indicate whether or not the probe and the target orientations matched.

four squares with a pattern of thick white and black oblique lines. These pattern masks subtended 2.6º × 2.3º of visual angle and were centered on each of the four location markers. The final display (the *probe display*) was similar to the second display, except that only one black oval was presented. This probe always appeared in the same location as a black oval in the target display. Half the time the probe matched the orientation of the target black oval that had preceded it, and half the time the probe mismatched it.

The subject's task was to decide whether the probe matched or mismatched the target. If the probe matched the target and the probe was in the LVF, the subject pressed the "z" key with the left hand. If the probe matched the target and the probe was in the RVF, the subject pressed the "/" key with the right hand. When a response was executed, the probe was extinguished, and after an intertrial interval of 1,350 msec, the next trial began. If the probe did not match the target, no response was to be made. On these trials, the probe was extinguished after 1,995 msec, and after an intertrial interval of 1,350 msec, the next trial began.

A single object, two objects in the same visual field (two-object unilateral display), and two objects in different visual fields (two-object bilateral display) were equally likely and were selected randomly from trial to trial. On single-object displays, the position of the target occurred at random and with equal probability in each of the four possible locations. For two-object unilateral displays, LVF and RVF presentations were equiprobable and randomly selected. For two-object bilateral displays, top, bottom, and diagonal field presentations were equiprobable and randomly selected. For two-object displays, the probe item appeared randomly and with equal probability at one of the target locations. On single-object displays, the probe always occurred at the location of the target. In all cases, target and probe orientations were equiprobable and randomly selected, and whether the probe orientation was the same as or different from the target orientation was equiprobable and varied randomly from trial to trial.

Each subject received 20 practice trials, followed by nine blocks of 64 trials. Approximately 1 h was required for the subject to complete the 696 trials (20 practice trials plus 576 test trials). The subjects were instructed to respond as accurately as possible. Speed was not emphasized.

Results

Response accuracy (proportion correct) was subjected to an analysis of variance with object display (one-object, two-object unilateral, or two-object bilateral), display time (100, 150, or 200 msec), and target visual field (left or right) as within-subjects factors and display distance (near or far) as a between-subjects factor. Performance in all the conditions is presented in Table 1.

Table 1
Mean Response Accuracies for Experiments 1, 2, and 3 as a Function of Target Visual Field (Left/Right) and Three Target Durations (e.g., 100, 150, and 200 msec in Experiment 1)

	Experiment 1					
	Left			Right		
Condition	100 msec	150 msec	200 msec	100 msec	150 msec	200 msec
Near						
One-object unilateral	.94	.94	.96	.95	.95	.95
Two-object unilateral	.79	.83	.85	.70	.77	.82
Two-object bilateral	.82	.87	.89	.82	.85	.87
Far						
One-object unilateral	.93	.95	.96	.91	.94	.94
Two-object unilateral	.79	.85	.91	.66	.72	.78
Two-object bilateral	.81	.87	.89	.77	.84	.87
	Experiment 2					
	Left			Right		
	60 msec	105 msec	150 msec	60 msec	105 msec	150 msec
One-object unilateral	.88	.92	.92	.85	.90	.94
Two-object unilateral	.77	.84	.87	.73	.79	.83
Two-object bilateral	.75	.86	.90	.79	.82	.90
	Experiment 3					
	Left			Right		
	60 msec	120 msec	180 msec	60 msec	120 msec	180 msec
One object	.67	.78	.84	.71	.79	.81
Two objects	.59	.68	.70	.59	.62	.67

Analysis revealed main effects for object display [$F(2,60) = 64.10$, $p < .0005$], display time [$F(2,60) = 45.24$, $p < .0005$], and target field [$F(1,30) = 25.63$, $p < .0005$], reflecting the fact that response accuracy improved when there was only one object, when the display time was lengthened, and when the target was in the LVF. There was no main effect of display distance [$F(1,30) = 0.09$, $p < 1$]. There was, however, a field $\times$ distance interaction [$F(1,30) = 5.41$, $p < .05$], indicating that the overall LVF advantage increased when elements were placed further afield. Display distance had no other effect on performance. In particular, there was no interaction between object display and display distance (all Fs < 1), suggesting that the object effects reflected object-based attention and were not merely an artifact of space-based attention (Vecera, 1994).

The interaction between interval and object was also significant [$F(4,120) = 8.82$, $p < .0005$]. As is indicated in Table 1, this was due to the fact that the performance improvement that was produced when display time was lengthened was much greater for two-object displays than for one-object displays, presumably because performance was near ceiling for the one-object display even at the shortest display duration.

The only other significant effect was an object $\times$ field interaction [$F(2,60) = 23.63$, $p < .0005$]. As is illustrated in Figure 2, this interaction reflects the fact that there was no difference between visual fields for one-object displays [$F(1,30) = 0.30$, $p < 1$] but that there was an advantage for the LVF in two-object displays. Planned contrasts showed that the LVF advantage was highly significant for the two-object unilateral display [$F(1,30) = 94.60$, $p < .0005$] and was marginally significant for the two-object bilateral display [$F(1,30) = 5.57$, $p < .05$]. Planned contrasts also revealed that performance for the two-object bilateral displays was higher than that for two-object unilateral displays. This effect was marginally significant for the LVF [$F(1,30) = 6.01$, $p < .05$] and was highly significant for the RVF [$F(1,30) = 96.37$, $p < .0005$].

Discussion

The goal of the present study was to investigate whether object-based attention effects differ between the cerebral hemispheres. To test whether our effects were specific to object-based attention, we manipulated stimulus distance, as was recommended by Vecera (1994). Our results revealed that response accuracy was higher for one-object than for two-object displays and that this two-object cost did not interact with manipulations to stimulus distance, suggesting that it is truly an object-based attention effect. In addition, the two-object cost was less pronounced when two items were presented between visual fields, rather than within the same field (two-object unilateral display), indicating that there is a performance benefit when both hemispheres commit attention to objects.

The most intriguing finding, however, was that the two-object cost was extremely severe when items were isolated to the RVF (left hemisphere). This finding suggests that the left hemisphere does not have a preferential bias for object-based attention, an interpretation that is at odds with the conclusions of Egly, Driver, and Rafal

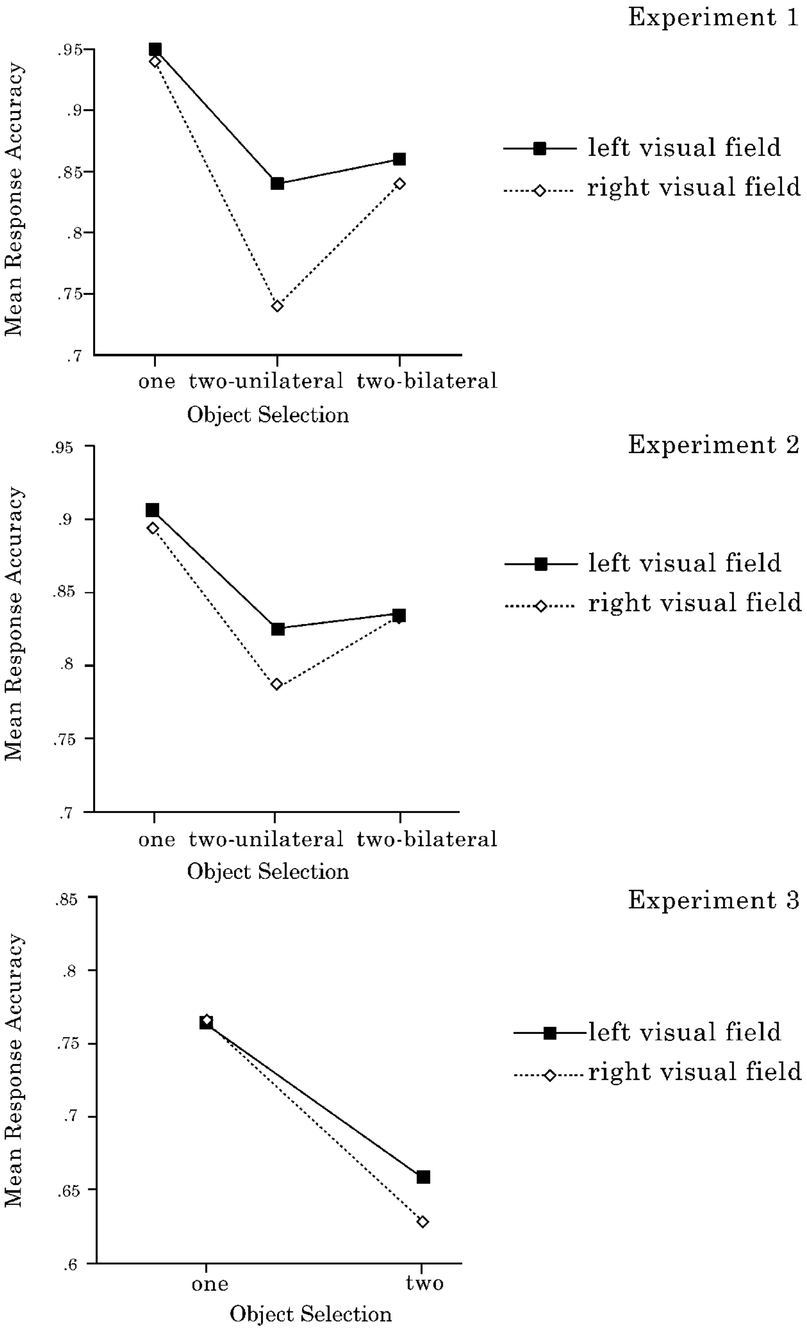

Figure 2. Mean response accuracy in Experiments 1, 2, and 3 as a function of target visual field and number of objects to be selected.

(1994) and Egly, Rafal, et al. (1994). Indeed, in contrast to this previous work, the present data suggest that the left hemisphere is particularly *poor* at committing attention selectively to multiple elements in its visual field.

There are several reasons, though, to question this interpretation of Experiment 1. First, distance was manipulated between groups, which may have weakened our ability to capture variations in object costs at different stimulus eccentricities. Consistent with this possibility is the fact that in the two-object unilateral condition, the advantage of the LVF over the RVF was larger in the far condition (.13) than in the near condition (.06), although this variation did not produce a higher order interaction. Second, the number of objects presented on any given trial was confounded with the number of stimulated locations. In other words, in the two-object condition, spatial attention had to be divided across two items, whereas in the one-object condition, it did not. Thus, our hemispheric differences in the unilateral condition might merely reflect the right hemisphere's ability to divide spatial attention between presented items, as compared with the left hemisphere. Such an interpretation would be consistent with the position that the right hemisphere is superior to the left hemisphere in orienting spatial attention (e.g., Davis & Schmit, 1973).

In Experiments 2 and 3, we examined whether object-based attention effects would continue to be lateralized to the right hemisphere when these concerns were addressed.

EXPERIMENT 2

In order to eliminate any potential confound between the number of items in the visual field and the number of possible target items, we presented objects at all four possible target locations on every trial. As in Experiment 1, target items were colored black, but now they co-occurred with nontarget items that were colored white. The subjects were instructed to attend only to the black objects. The task was again to report whether the probe and the target objects matched. Note that because there was an object in every location and target candidates differed from nontarget candidates solely on the basis of a nonspatial object attribute (color contrast), target selection had to be object based, rather than space based.

Second, and as a particularly rigorous test of our initial findings, we replaced our Experiment 1 oval-shaped stimuli with letter stimuli. One might argue that the oval-shaped stimuli we had used were, for some unspecified reason, better suited for a nonlinguistic right hemisphere than for a language-based left hemisphere and that this is why we obtained a right-hemisphere advantage in Experiment 1. In Experiment 2, we eliminated this concern because, if anything, letter stimuli should be preferred by the language-based left hemisphere (Fecteau, Enns, & Kingstone, 2000).

Method

Methodological details were the same as those in Experiment 1, except where indicated. Twenty new undergraduate students were tested. The display sequence was the same, with the exception that black or white Zs or Ns (1.3º × 1.3º) were presented in all four of the location markers 6º away from central fixation. Possible target letters were colored black, and nontargets were colored white. Display durations were now 60, 100, and 150 msec, since pilot work had revealed that response performance was near ceiling with the slightly longer range of display durations in Experiment 1. In all other respects, the task was the same as before. For example, if the probe letter did not match the target letter, no response was made. If the probe and the target letters were the same, however, either a right or a left key was pressed, depending on the field of the probe letter.

Results

The data were analyzed as in Experiment 1. Performance in all the conditions is presented in Table 1. Main effects for object display [$F(2,38) = 30.60$, $p < .001$], display time [$F(2,38) = 41.67$, $p < .001$], and target field [$F(1,19 = 4.89$, $p < .05$] were all significant, demonstrating that, as in the first experiment, response accuracy improved when there was only one object, when the display time was lengthened, and when the target was in the LVF. Therefore, despite the fact that the number of items presented on each trial was held constant in Experiment 2 and letter stimuli had replaced the oval stimuli, the right hemisphere continued to outperform the left hemisphere.

Both the field × interval [$F(2,38) = 0.70$, $p > .05$] and the interval × object [$F(4,76) = 2.08$, $p > .05$] interactions were nonsignificant. Importantly, and as is shown in Figure 2, the field × object performance pattern was almost identical to that in Experiment 1. This interaction nudged significance [$F(2,38) = 2.80$, $p < .07$], and planned comparisons confirmed that, as in Experiment 1, there was a highly significant LVF advantage for the two-object unilateral displays [$F(1,18) = 11.16$, $p < .005$]. Planned contrasts also showed that, as before, there was no significant two-object bilateral versus two-object unilateral advantage for the LVF [$F(1,18) = 0.610$, $p > .5$] but that this effect was highly significant for the RVF [$F(1,18) = 15.740$, $p < .001$].

Discussion

The primary motivation for Experiment 2 was to determine whether the object effects and hemispheric differences observed in Experiment 1 would reemerge when a possible confound between object and location number was controlled and letter stimuli were presented. The same effects were found, with the key finding being that the two-object cost was particularly severe when two target items were isolated to the RVF (left hemisphere). Because (1) items were presented in every location on every trial, (2) target selection was based on a nonspatial target attribute, and (3) stimulus form (i.e., letters) should favor left-hemisphere processing, it is reasonable that the results in Experiments 1 and 2 be attributed to an object-based selection advantage in the right hemisphere.

It is still possible, though, to contrive a *spatial* attention explanation for the right-hemisphere advantage on two-object unilateral displays. Such an account might posit that although the selection of a target is based on nonspatial attributes, shifting attention from one target to the other requires spatial reorienting and that it is this act of reorienting that is superior in the right hemisphere. To address directly spatial explanations of this type, we ran a final experiment that was closely modeled on the original Duncan (1984) paradigm in which overlapping target items were used. It has been demonstrated repeatedly that in this paradigm, spatial attention accounts are not viable. Thus, if a right-hemisphere advantage was found to persist, we could attribute this lateralization to object-based attention.

EXPERIMENT 3

Two overlapping target items were presented at random to either the LVF or the RVF. The subjects were required to attend to only one of the two target items (one-

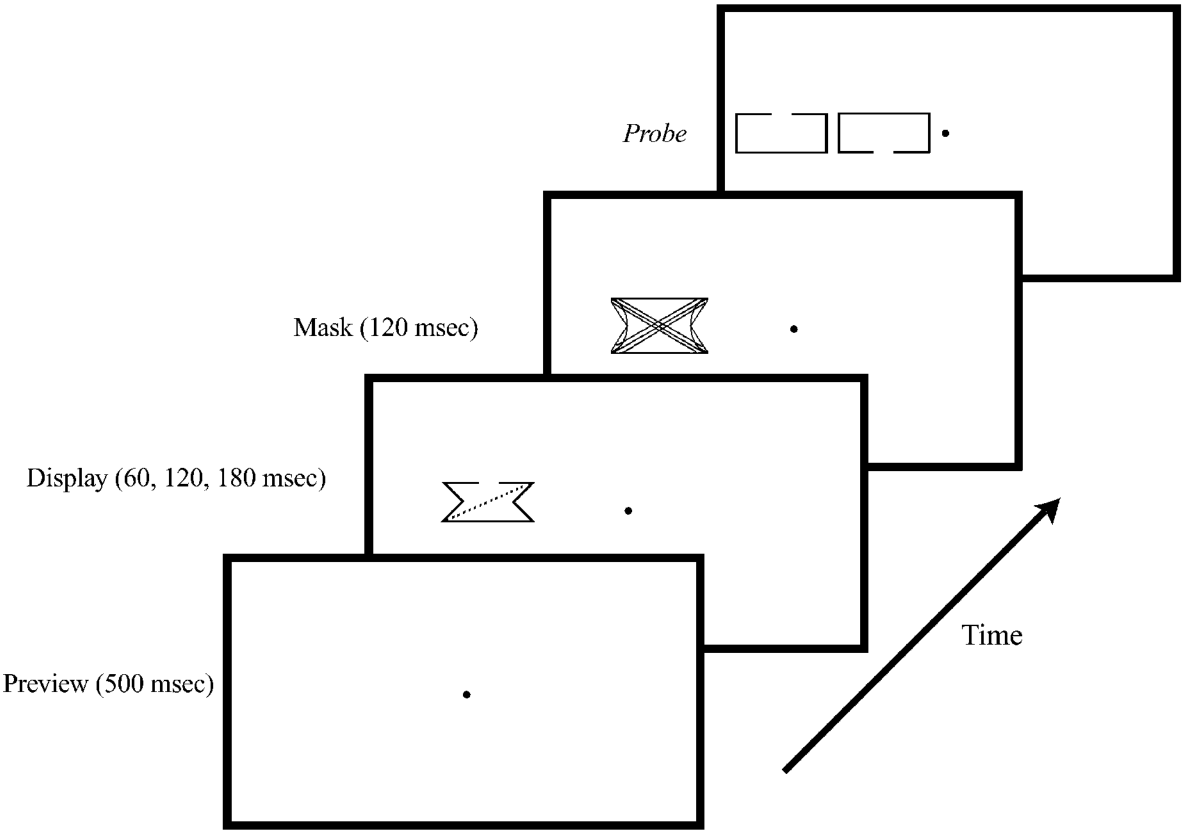

Figure 3. Example of the sequence of events in Experiment 3 on a typical trial. Each trial began with the presentation of a central fixation point. After 500 msec, two overlapping objects would appear on the left or the right for 60, 120, or 180 msec. Each object, a box and a slanted line, had two attributes that were relevant if the object was probed: gap location (top/bottom) and side concaveness (pointed/curved) for the box, slant and texture (dotted/dashed) for the line. The objects were masked for 120 msec, and then, depending on the task, one of the two relevant attributes for an object was probed in the same field as the target display. The task was to indicate with an unspeeded response which of the probes matched the target attribute (e.g., the left probe has a top gap, as does the target, in the present illustration).

object blocks) or to both items (two-object blocks). As in the previous two experiments, at the end of each trial, the subjects were probed for their correct knowledge on one of two target attributes.

Method

Methodological details were the same as those in the previous experiments, except where indicated. Twenty new undergraduate students were tested. The display sequence is illustrated in Figure 3. The fixation preview display was presented for 500 msec. Overlapping target items—a box and a line—subtending 5.5° × 3.0° were then presented randomly to the left or right of center by 9° (fixation to middle of overlap). Each target item contained two attributes that varied randomly from trial to trial. For the box, the gap might be on the top or the bottom, and its concave sides were either curved or pointed. For the line, it sloped down from top left to bottom right or vice versa and was dotted or dashed. Display durations were now 60, 120, and 180 msec. A target mask composed of all possible display items, jittered by 0.25°, was then presented for 120 msec at the location of the target items. A probe display was then presented in the same field as the target items and mask. This probe display consisted of two items positioned side by side that differed only on the attribute that was to be judged. When the gap on the box was to be judged, rectangles with the gap on the top and bottom were presented; when the sides of the box were to be judged, the concave sides were curved on one rectangle and pointed on the other. When the angle of the line was to be judged, two solid lines were presented side by side, with one line sloping down from top left to bottom right and the other sloping in the reverse direction. When the texture of the line was to be judged, the adjacent lines were vertical, with one dotted and the other dashed. When the probe display was on the left, the subjects made an unspeeded left-handed two-alternative choice, using “z” and “x” to indicate whether the target had possessed the relevant attribute of the left probe or the right probe (in Figure 3, the correct response would be a “z” response, to indicate the left rectangle with the gap on the top). When the probe display was on the right, the right hand was used to press “.” or “/” to indicate the left or the right probe, respectively.

In different blocks of trials, the subjects were required to attend to the relevant attributes of the box or the line (one object) or both the box and the line (two objects). The order of these conditions was counterbalanced across subjects. Each condition was composed of 184 trials divided equally between two blocks. Forty-three practice trials preceded testing in each condition.

Results

Performance for one- and two-object displays are presented in Table 1. Main effects for object display [$F(1,19) =$

51.45, $p < .001$], display time [$F(2,38) = 63.11$, $p < .001$], and target field [$F(1,19) = 4.51$, $p < .05$] were all significant. This demonstrates that as in the previous experiments, response accuracy improved when selection was for one object, when the display time was lengthened, and when items were presented to the LVF (right hemisphere).

As is shown in Figure 2, this LVF/right-hemisphere advantage was revealed when object selection across the two objects was required, thus producing a highly significant field × object interaction [$F(1,19) = 6.142$, $p < .025$]. Because the two objects occupied the same location, this object-based attention effect cannot be attributed to a right-hemisphere advantage for spatial orienting. Thus, the present data provide conclusive evidence, and converge with our previous findings, that object-based attention is preferentially lateralized to the right hemisphere.

No other higher order effect was significant, except for a field × time interaction [$F(2,38) = 4.65$, $p < .05$] reflecting that the right-hemisphere performance advantage increased in magnitude as display duration increased.

Discussion

The present experiment, in conjunction with the previous two experiments, provides compelling evidence that the left hemisphere is particularly poor at committing attention selectively to more than one object in the visual field. This is true even when target items are presented alone in the visual field at different spatial locations (Experiment 1), when they are letter stimuli and target selection cannot be based on spatial attributes (Experiment 2), and when items are overlapping in the same physical space (Experiment 3). The results of each experiment converged on the conclusion that the effects reflected object-based selection, rather than space-based selection. Thus, in agreement with Egly and colleagues (Egly, Driver, & Rafal, 1994; Egly, Rafal, et al., 1994) our data show that object-based attention is a specialized form of orienting that is subserved by lateralized cortical brain mechanisms. Contrary to the conclusions of Egly and colleagues, however, our data indicate that the right hemisphere—and not the left hemisphere—is preferentially biased for committing object-based attention to elements in the visual environment.

To our knowledge, the present investigation represents the first examination of purely object-based attention effects across the cerebral hemispheres. The goal of future research will be to isolate the specific brain mechanisms subserving object-based attention by testing patient populations (e.g., focal lesion and split-brain patients) and/or by functional neuroimaging of healthy individuals. We expect that the paradigm utilized in the present investigation should be amenable to these future lines of research.

REFERENCES

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

Davis, R., & Schmit, V. (1973). Visual and verbal coding in the interhemispheric transfer of information. *Acta Psychologica*, **37**, 229-240.

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

Duncan, J. (1993). Coordination of what and where in visual attention. *Perception*, **22**, 1261-1270.

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

Egly, R., Rafal, R., Driver, J., & Starrveveld, Y. (1994). Covert orienting in the split brain reveals hemispheric specialization for object-based attention. *Psychological Science*, **5**, 380-383.

Enns, J. T., & Kingstone, A. (1997). Hemispheric coordination of spatial attention. In S. Christman (Ed.), *Cerebral asymmetries in sensory and perceptual processes* (pp. 197-231). Amsterdam: Elsevier, North-Holland.

Fecteau, J. H., Enns, J. T., & Kingstone, A. (2000). Competition-induced visual field differences in search. *Psychological Science*, **11**, 386-393.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, **32**, 3-25.

Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, **109**, 160-174.

Vecera, S. P. (1994). Grouped locations and object-based attention: Comment on Egly, Driver, and Rafal (1994). *Journal of Experimental Psychology: General*, **123**, 316-320.

Vecera, S. P., & Farah, M. J. (1994). Does visual attention select objects or locations? *Journal of Experimental Psychology: General*, **123**, 146-160.

(Manuscript received May 16, 2000;
revision accepted for publication January 6, 2003.)