Stimulus Discrimination Following Covert Attentional Orienting to an Exogenous Cue

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Five experiments explored exogenous covert visual–attentional orienting following a brief peripheral cue. On each trial an attentional cue was followed by a stimulus in an empty field at 1 of 8 locations on an imaginary circle centered on the fixation point. The cued area size and the cue–target spatial relation were manipulated. Accuracy and response time were affected by the exogenous cue validity. Attention was allocated to a specific location in a visual quadrant: A target at an uncued location in a quadrant was not facilitated as much as a target at the cued location, and a target in a different quadrant was inhibited in relation to a neutral condition. Cuing 2 locations in a quadrant was not as facilitative for targets at the cued locations or as inhibitive for targets at other locations compared with cuing a single location in a quadrant. Results are discussed in the context of several extant models of covert visual–spatial attention.

The ability of the human observer to orient spatial attention covertly without overtly orienting the eyes has been explored at least since the time of Helmholtz, Wundt, and James (e.g., see James, 1890/1950). More recently, evidence has been accumulating that there may be two somewhat independent visual–spatial attentional systems, each with its own functional characteristics and neurophysiological substrate. These two systems can be referred to as the *exogenous* and *endogenous* systems (Briand & Klein, 1987; Posner, 1980). Some of the potential functional differences between the two systems (respectively) are reflexive responsiveness to peripherally presented transient cues versus voluntary responsiveness to symbolic cues (Jonides, 1981; Jonides & Yantis, 1988; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Yantis & Jonides, 1984), quick but brief versus slower-acting but sustained response functions (Jonides, 1981; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989; Posner & Cohen, 1984), relatively large versus small cuing effects (Jonides, 1981; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989), inhibition of return versus no inhibition of return effects (Maylor, 1985; Posner & Cohen, 1984; Rafal, Calabresi, Brennan, & Sciolto, 1989), and relation versus no relation to the eye movement programming system (Rafal et al., 1989). There is also evidence that the neurophysiological substrates for the exogenous and endogenous systems involve midbrain (pretectum, superior colliculus) and geniculostriate (parietal) pathways, respectively (Posner, Cohen, & Rafal, 1982; Rafal et al., 1989;

Robinson & Peterson, 1986; Wurtz, 1985). Although this broad sketch of the two systems is likely to be overly simplistic, it is clear that viewing visual–spatial attention as a single construct is no longer sufficient. A majority of the research exploring visual–spatial attention either has been concerned with the endogenous system or has not distinguished between the two systems.

Two general models of visual–spatial attention have recently been proposed to explain the results commonly observed in orienting studies. First, the *zoom-lens* model developed by Eriksen and his colleagues (C. W. Eriksen & St. James, 1986; C. W. Eriksen & Yeh, 1985) proposes that visual attention is a limited-resource system and that available resources can be directed to bounded regions of space that vary in size. Increasing the size of the attended region spreads available resources over a greater area and thus reduces the "resolving power" at any particular location within the attended region. Because the zoom-lens model is a variant of Posner's *spotlight* metaphor of attention (Posner, 1980; Posner, Snyder, & Davidson, 1980), an additional assumption is that if a stimulus beyond the focus of attention is to be identified, then the focus of attention must shift to that location. The time needed to identify a stimulus within the focus of attention depends on how narrowly attention has been focused, and the time needed to identify a stimulus outside of the attentional focus depends on the time required to reorient attention to that location.

Similarly, the *gradient* model of attention developed by LaBerge and Brown (1989; see also Downing & Pinker, 1985; Shulman, Wilson, & Sheehy, 1985) assumes that visual attention is a limited-resource system that can be directed to regions of space of varying size. Unlike the zoom-lens model, however, LaBerge and Brown (1989) proposed that resources fall off continuously from the center of the focus of attention (the peak in the attentional gradient) as a function of spatial distance, so the resources allocated to a given location depend on the distance of that location from the peak in the gradient. Because resources decrease with increasing distance, and because the rate of processing at a location is assumed to depend

on the resources allocated to that location (LaBerge & Brown, 1989), stimulus identification time varies with distance from the gradient peak.

In the present study I explore several basic issues of attentional orienting with a paradigm designed to favor the exogenous system and thereby test the generalizability of the zoom-lens and gradient models. On each trial a target stimulus (an X or an O) appeared at one of eight locations (two per visual quadrant) positioned on an imaginary circle centered on the point of fixation. Prior to target presentation, a location cue briefly appeared. The target then appeared either at the same location or at a different location from the cue. The subjects' task following presentation of the target was to push one of two buttons indicating whether an X or an O had appeared on that trial.

This basic paradigm was used to explore several issues concerning exogenous attentional orienting. First, earlier studies tended to use either stimulus detection in a blank field (e.g., Maylor, 1985; Posner, 1980; Rafal et al., 1989) or stimulus discrimination in a field of distractors (e.g., B. A. Eriksen & C. W. Eriksen, 1974; Eriksen & Hoffman, 1972, 1973; Müller & Rabbitt, 1989; Nakayama & Mackeben, 1989) to explore issues of attentional orienting. It has been argued that attentional effects are relatively weak when the task requires stimulus discrimination in an otherwise blank field (Posner, 1980; van der Heijden, Schreuder, & Wolters, 1985). The question therefore arises whether an effect of exogenous attentional orienting would be found at all in the present paradigm, and if so, whether this effect can be shown to be relatively robust.

Second, it has generally been assumed that attention can be selectively allocated to a specific and limited region of the visual field (or more appropriately, to that aspect of the internal representation of space that represents a specific region). This basic tenet was recently challenged in a series of studies reported by Hughes and Zimba (1985, 1987; but see Klein & McCormick, 1989; McCormick & Klein, in press). These researchers reported that a target appearing either in the same lateral hemifield (Hughes & Zimba, 1985) or in the same quadrant (Hughes & Zimba, 1987) of the visual field as an attended location were responded to as quickly as a target appearing at the specific cued location. Hughes and Zimba argued from these data and from neurophysiological considerations that spatial attention may only be directed to fairly large areas of the visual field (such as a hemifield or a quadrant) and not to specific locations within these broad regions.

Whether attention can be allocated to particular locations or must instead be more generally allocated to large regions of the visual field is clearly important to the architecture of the visual system. Many theories of vision assume that selectivity can (or must) be restricted to a limited region of space. For example, it has been proposed that attentional focus is necessary for the proper operation of processes leading to stimulus identification (Bergen & Julesz, 1983; Treisman & Gelade, 1980) or response selection (Duncan, 1981) and that restricted spatial processing is necessary to prevent cross talk between nearby spatial channels (Pollatsek & Digman, 1977). Both of the models of visual attention outlined before (the

zoom-lens and gradient models) assume that attention can be focused on a limited area.

In addition, several hypotheses relating covert orienting and eye movement control have assumed that attention can be directed to selected locations in the visual field (e.g., Henderson, 1988; Henderson & Ferreira, 1990; Henderson, Pollatsek, & Rayner, 1989; McConkie, 1979; Morrison, 1984; Rayner & Pollatsek, 1989). Given the recent evidence suggesting that eye movement control is more intimately tied to the exogenous attentional system than the endogenous system (Rafal et al., 1989), it seems worthwhile to determine whether exogenously oriented attention can be allocated to a specific location within a visual quadrant. The paradigm used here allowed exploration of the issue of spatial selectivity because when a target appeared at an uncued location, it could be in one of three relations to the cued location: (a) in the opposite lateral hemifield, (b) in the opposite vertical hemifield, or (c) in the opposite lateral and vertical hemifields. In addition, when a target appeared at an uncued location following a small cue, the target could appear in the same lateral and vertical hemifield (i.e., in the same quadrant) as the cue but at a different location. If attention can be allocated to a specific location within a quadrant following an exogenous cue, then a target appearing at the specific cued location ought to show facilitated performance compared with a target appearing at another location within the cued quadrant.

Finally, it has been suggested that the size of the spatial region affected by attentional orienting can be strategically changed depending on the demands of the task (C. W. Eriksen & St. James, 1986; C. W. Eriksen & Yeh, 1985; LaBerge, 1983; LaBerge & Brown, 1989; Posner et al., 1980). Because these studies have all employed paradigms that are most likely to have involved the endogenous orienting system, it is not currently known whether the size of the region to which attention has been exogenously oriented is flexible. This is important because it addresses the generalizability to the exogenous orienting system of the zoom-lens and gradient models as they are currently formulated. To determine whether exogenous cues can induce attentional orienting to regions of varying size as expected according to the zoom-lens and gradient models, and to explore the nature of such region-size effects if they occur, the experiments reported in this article used two cue-size conditions. Small cues consisted of an underline at one target location; large cues consisted of an underline at two target locations within a visual quadrant. If attention can be exogenously drawn to regions of variable size, then performance at the nonattended location within the cued quadrant ought to be worse than performance at the cued location when the cue is small, but performance at both locations within the cued quadrant ought to be equal when the cue is large. In addition, performance at a cued location is expected to be poorer following a large compared with a small cue because in the former case attentional resources are less densely allocated over a greater area.

Experiment 1

In Experiment 1 I explored three issues related to the allocation of covert visual–spatial attention. First, does pres-

entation of an exogenous cue produce a pattern of facilitation at cued locations and inhibition at uncued locations for target discrimination in an otherwise blank field? Second, is attention oriented to a large region of the visual field (e.g., a hemifield or quadrant) following an exogenous cue, or is target discrimination at a specific cued location within a quadrant of the visual field facilitated over another location within that same quadrant? Third, can the attended area of the visual field be enlarged and narrowed from trial to trial depending on the nature of the exogenous cue, and if so, what effect does the spatial extent of attention have on discrimination processes?

To explore these issues, targets could appear at eight possible locations (two per visual field quadrant) situated on an imaginary circle and therefore equally distant from the point of fixation. The exogenous cues consisted of an underline that appeared below a target position prior to presentation of the target. Two cue sizes were used: The small cue consisted of an underline at a single target location and the large cue consisted of an underline at each of the two target locations within a quadrant. Several types of invalid-cue trials were used. First, for both small- and large-cue conditions, the target could appear in a noncued quadrant that was either in the same lateral hemifield as the cue (the opposite lateral hemifield) or in the quadrant diagonal to the cued quadrant. If attention is allocated to a lateral hemifield (Hughes & Zimba, 1985), then performance for targets appearing in the same lateral hemifield but different quadrant as the cue ought to be facilitated as much as performance for targets in the same quadrant as the cue and ought to be facilitated over performance for targets in the other two noncued quadrants. Second, for the small-cue condition, the target could appear in the same quadrant as the cue but at the other location in the quadrant. If attention is allocated to a visual quadrant (Hughes & Zimba, 1987), then performance for targets appearing in the same quadrant as the cue ought to be facilitated as much as performance for targets appearing at the specifically cued location. On the other hand, if attention is oriented to a specific location following presentation of an exogenous cue, then targets appearing in an uncued quadrant ought to perform more poorly than targets appearing in the cued quadrant, and targets appearing in the same quadrant as the cue but at a different location ought to perform more poorly than targets at the cued location.

A neutral cue (consisting of the appearance of an underline at all eight target locations) was also used to allow an assessment of costs and benefits produced by valid and invalid cues.

Method

Subjects. Twelve University of Alberta (Edmonton, Alberta, Canada) undergraduate students participated for credit toward their introductory psychology class. All subjects had normal or corrected-to-normal vision.

Apparatus and stimuli. Stimuli were presented black on white on a high-resolution color video monitor placed 35 cm from the subject. A chin and forehead rest was used to maintain viewing distance. The target stimuli were the capital letters X and O, which were created in a 7 × 12 pixel matrix 1° of visual angle high and 44 min wide. The

spatial masking stimulus consisted of the same two characters superimposed. The location cue was an underline 15 min high and 1° 20 min wide. The distance from the bottom of the target position to the top of the cue was 30 min. The underline appeared at one target location in the small-cue condition and at the two locations in the same quadrant in the large-cue condition.

Stimuli could be displayed at eight locations around an imaginary circle centered at the point of fixation. The eight locations were arranged so that two locations appeared in each quadrant of the circle. The center of each target location was 8° 30 min from the fixation point. Target locations within a quadrant were 5° 24 min center to center, and nearest-neighbor target locations across quadrants were 7° 36 min center to center.

Subjects responded by pressing the appropriate microswitch located on a table-mounted response panel. The response panel was interfaced with a dedicated I/O board; pressing a button on the response panel generated a system interrupt and stopped a millisecond clock. Stimulus presentation and response collection were controlled by a Zenith 80286 microcomputer.

Procedure. Subjects were asked to judge the identity of a target stimulus viewed peripherally. Each trial began with presentation of a central fixation cross along with the mask stimulus indicating the eight possible target locations. When subjects were ready, they pushed a button to start the trial. The central fixation cross was then displayed alone for 1,000 ms. A location cue appeared for 100 ms, followed by a target stimulus (X or O) for 67 ms. A spatial mask followed the target and remained on the screen; the mask consisted of a superimposed X and O at each of the eight possible target positions. Each display immediately followed the preceding display (i.e., 0 ms interdisplay interval), and the stimulus on the preceding display was extinguished with the onset of the next display (i.e., the location cue was removed with the onset of the target), although the fixation cross remained visible throughout the trial. Subjects executed a forced-choice response following target onset by pressing one of two response keys. After the response there was a minimum 2,000-ms intertrial interval, after which subjects could press a key to begin the next trial.

At the beginning of a session, subjects were informed about the general aspects of the procedure. The rapidity of the visual events was discussed, and the subjects were encouraged to pay careful attention to the display on each trial. Response accuracy was stressed. Subjects were told that attending to the cued location would improve performance, although specific target probabilities across conditions were not mentioned. Subjects were further informed that they would not be able to move their eyes fast enough to look at the target, and they were therefore encouraged to maintain fixation at the center of the screen. The first few practice trials convinced subjects that maintaining fixation was the best strategy.[1]

Location cues were small or large. The small cue consisted of a single location cue; the large cue consisted of the simultaneous display of the two location cues within a quadrant. Large cues informed subjects that the target was likely to appear in a particular quadrant but did not specify which of the two locations within the quadrant was most likely. Given that the target did appear in the quadrant specified by a large cue, it was equally likely to appear in either of the two locations within that quadrant. On the other hand, small cues informed subjects both that the target was likely to appear in a

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[1] In experiments in which subjects are induced to move their eyes as quickly as possible, the mean eye movement latency is generally more than 200 ms, and the minimum latency plus saccadic duration is also greater than the 167-ms total display duration used in the current experiment (e.g., see Abrams, Meyer, & Kornblum, 1989; Henderson, Pollatsek, & Rayner, 1987; Rayner, Slowiaczek, Clifton, & Bertera, 1983).

particular quadrant and that if the target did appear in that quadrant, it would appear at that specific location 60% of the time. The other 40% of the time, the target appeared in the other within-quadrant location.

Given a small location cue, the target appeared in the cued location with .375 probability, at the other location in the quadrant with .25 probability, and in one of the other three quadrants with .375 probability (.0625 probability for each of the other six locations). Given a large location cue, the target appeared in the cued quadrant with .50 probability (.25 probability at each of the two locations within the quadrant). When the target did not appear in the cued quadrant, it appeared in one of the other three quadrants with .50 probability (.0833 probability for each of the other six locations). Thus, small cues were slightly more predictive of the quadrant within which the target would appear (.625 vs. .50).

The experiment contained 256 trials broken down as follows. For valid trials, the target could be cued by a large or small cue, could appear in one of four quadrants, could appear in one of two locations within the quadrant, and could be one of two targets. Thus there were 2 (cue type) × 4 (quadrant) × 2 (location) × 2 (target) = 32 valid trial types. Three of each of these trial types were given for 96 valid trials. For invalid trials, the target could be (erroneously) cued by a large or small cue. When the cue was small and invalid, the target could appear inside the same quadrant or in a different quadrant. For the small-cue invalid-target-inside condition, the target could appear in one of four quadrants, could appear in one of two locations in a quadrant, and could be one of two targets. Thus there were 4 (quadrant) × 2 (location) × 2 (target) = 16 small-cue within-quadrant invalid trial types. Each of these trial types was repeated twice for 32 trials. When the small cue was invalid and the target was in a different quadrant, the cue could appear in one of four quadrants and in one of two locations in a quadrant; the target could appear in one of three spatial relationships to the cue (same hemifield, different hemifield, or diagonal) at one of two locations in a quadrant and could be one of two targets. There were therefore 4 (cue quadrant) × 2 (cue location) × 3 (target hemifield) × 2 (target location) × 2 (target) = 96 small-cue outside-quadrant invalid trial types. To reduce the total number of trials and equate the number of small- and large-cue outside-quadrant invalid trials, only half (48) of these possible 96 small-cue outside-quadrant invalid trials were used. This was accomplished through the use of only one of the two target locations within a quadrant. The target locations were chosen so that distance from the cue location was counterbalanced across quadrant. Finally, when the large cue was invalid, the cue could appear in one of four quadrants; the target could appear in one of three spatial relationships to the cue at one of two locations in a quadrant and could be one of two targets. There were therefore 4 (cue quadrant) × 3 (target hemifield) × 2 (target location) × 2 (target) = 48 large-cue invalid trial types. Each of these trial types occurred once. Finally, there were 32 neutral trials: 8 target locations and 2 targets at each location, or 16 trial types, each repeated twice. The neutral-cue condition consisted of the simultaneous display of all eight location cues.

Each session began with the instructions along with several example trials, followed by 32 practice trials and one test block. The entire experiment lasted about 45 min.

Results

Analyses were conducted on the mean percentage of correct responses and mean response times for correct responses.

Percentage correct. Figure 1 shows the mean accuracy rates as a function of cue size and cue validity, with invalid trials shown as a function of hemifield location in relation to the cue (excluding the within-quadrant invalid and neutral
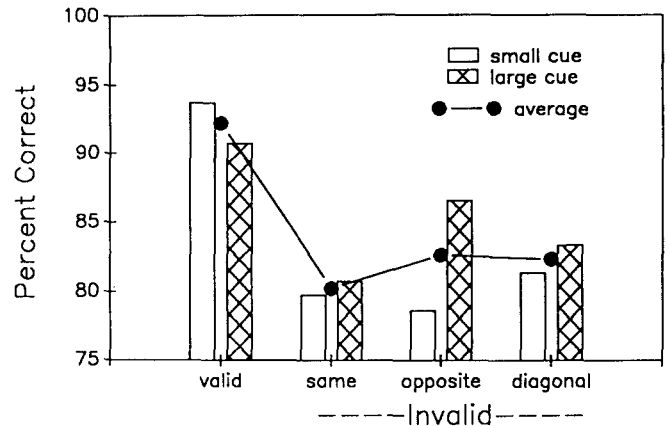

Figure 1. Mean response accuracy as a function of cue validity (by location) and cue size for Experiment 1. (Performance for neutral trials and within-quadrant invalid trials is not shown. *Same* denotes the quadrant in the same lateral hemifield but opposite vertical hemifield, *opposite* denotes the quadrant in the opposite lateral hemifield but same vertical hemifield, and *diagonal* denotes the quadrant in the opposite lateral and vertical hemifields.)

conditions). As an overall test of the sensitivity of the paradigm to the exogenous attentional cues, the main effect of cue validity was examined. Mean accuracy rate was .92 when the target appeared at the cued location and .82 when the cue appeared in another quadrant, $F(1, 11) = 7.68$, $MS_e = 0.0349$, $p < .05$.

Two analyses were relevant for determining whether attention following an exogenous cue is oriented to a specific location rather than to a lateral visual hemifield or visual quadrant. First, through the examination of just the outside-quadrant invalid trials (i.e., excluding the within-quadrant invalid condition), I conducted an analysis that treated the data as a 3 (hemifield location) × 2 (cue size) factorial design. In this analysis, there was no main effect of hemifield location, $F < 1$; a marginal effect of cue size, $F(1, 11) = 3.80$, $MS_e = 0.0126$, $.05 < p < .10$; and no significant interaction between the two, $F(2, 22) = 1.26$, $MS_e = 0.0126$, $p > .30$. Clearly (as can be seen in Figure 1), to the extent that there is any difference at all across hemifields, performance in the same lateral hemifield condition was worse than in the other two conditions.

The second test for specific spatial selectivity involved the within-quadrant invalid condition shown in Table 1. Planned comparisons revealed that performance in the within-quadrant invalid condition was significantly poorer than performance in the small-valid-cue condition, $F(1, 11) = 11.7$, $MS_e = 0.0134$, $p < .01$, and did not differ significantly from performance in the small-invalid-cue condition, $F < 1$. This result is consistent with the hypothesis that attention is oriented to a specific location and is incompatible with the hypothesis that attention can only be allocated to an entire visual quadrant.

The final issue explored in this experiment was whether small exogenous cues facilitate performance more than do large exogenous cues. To investigate this issue, I conducted a

Table 1

Mean Accuracy (Percentage Correct) and Response Time (RT) for Trials in Experiment 1

Condition	Mean performance		Performance versus neutral condition	
	% Correct	RT (in ms)	% Correct	RT (in ms)
Small valid cue	94	578	7**	112***
Small invalid cue	80	728	−7*	−38*
Within-quadrant invalid	82	701	−5*	−11
Large valid cue	91	621	4*	69**
Large invalid cue	84	746	−3	−56*
Neutral cue	87	690	—	—

Note. Performance in the small- and large-invalid-cue trials has been collapsed over hemifield location. Negative numbers indicate poorer performance in comparison to the neutral condition.
* $p < .10$. ** $p < .05$. *** $p < .01$.

separate analysis that treated the experiment as a 2 (cue size) × 2 (cue validity) factorial design and excluded the neutral and within-quadrant invalid conditions. In this analysis, the Cue Size × Cue Validity interaction was marginally significant, $F(1, 11) = 4.29$, $MS_e = 0.0062$, $.05 < p < .10$. As can be seen in Table 1, the marginal interaction was because the difference between valid and invalid trials when the cue was large was not as great as when the cue was small.

Table 1 includes a comparison of the costs and benefits associated with each of the other conditions in relation to the neutral condition. Performance in the neutral condition tended to be intermediate between performance in the valid and invalid conditions.

Response time. Response time analyses included only correct trials. In addition, outlier response times less than 100 ms, greater than 3,000 ms, or more than three standard deviations from the cell mean for that condition and that subject were discarded to reduce variability. In total, 3% of the data were categorized as outliers.

As in the accuracy data, there was a reliable effect of cue validity, $F(1, 11) = 11.4$, $MS_e = 39,643$, $p < .01$. Mean response time was 600 ms and 739 ms, respectively, for valid and invalid trials.

Figure 2 shows the response time data as a function of cue size and cue validity (excluding the within-quadrant invalid and neutral conditions), with invalid trials shown as a function of target hemifield location. For the invalid trials, neither the effect of cue size nor quadrant was significant, $Fs < 1$, nor was there an interaction, $F(2, 22) = 1.63$, $MS_e = 12,240$, $p > .20$. Clearly, there was no suggestion of a difference between the same versus different hemifield conditions.

The data for the within-quadrant invalid condition also mirrored the accuracy data, as can be seen in Table 1. Performance in the within-quadrant invalid condition was significantly poorer than performance in the small-valid-cue condition, $F(1, 11) = 6.02$, $MS_e = 30,092$, $p < .05$, but did not differ significantly from performance in the small-invalid-cue condition, $F(1, 11) = 1.11$, $MS_e = 8,067$, $p > .30$.

In the analysis examining cue size and cue validity collapsed over hemifield (and excluding the neutral and within-quadrant invalid conditions), the interaction of cue size and cue

validity was not significant, $F(1, 11) = 2.50$, $MS_e = 1,637$, $p > .10$. As can be seen in Table 1, however, there was again a tendency for the large cues to produce a smaller performance difference between the valid and invalid conditions compared with the small cues. There was also a marginal main effect of cue size, $F(1, 11) = 4.72$, $MS_e = 4,803$, $p = .05$, with responses in the small-cue condition faster than responses in the large-cue condition.

Table 1 shows the response time costs and benefits associated with each of the other conditions in relation to the neutral condition. These data mirrored the accuracy data and again showed performance in the neutral condition to be roughly intermediate between performance in the valid and invalid conditions.

Discussion

The results of this experiment pertain to the three questions raised in the introduction. First, a robust effect of exogenous cuing was demonstrated through the use of a target discrimination task in an otherwise blank field. Contrary to prior claims (e.g., Posner, 1980; van der Heijden et al., 1985), attentional effects on stimulus discrimination in a blank field need not be small. Note that large cuing effects were found with the small cues even though the small cues were not very predictive of the target location. This finding is consistent with the view that exogenous cues automatically orient attention to the cued location (Jonides, 1981).

The second question addressed in this experiment was whether covert orienting following an exogenous cue is directed to a specific location within the visual field or is instead directed to a larger region such as a visual quadrant or a visual hemifield. The data showed no difference in either accuracy or speed of response during invalid trials, depending on the
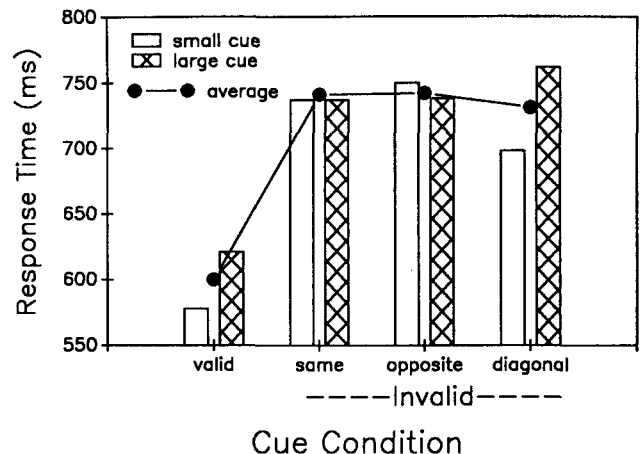

Figure 2. Mean response time as a function of cue validity (by location) and cue size for Experiment 1. (Performance for neutral trials and within-quadrant invalid trials is not shown. *Same* denotes the quadrant in the same lateral hemifield but opposite vertical hemifield, *opposite* denotes the quadrant in the opposite lateral hemifield but same vertical hemifield, and *diagonal* denotes the quadrant in the opposite lateral and vertical hemifields.)

relationship of the quadrant in which the target appeared to the quadrant that was cued. These data thus do not support the view that the entire lateral hemifield within which a cue appears will be facilitated. Furthermore, because performance as assessed by both accuracy and speed was significantly worse when the target appeared at the uncued location within the cued quadrant than performance when the target was at the specific cued location, the data do not support the view that attention was allocated to the entire quadrant within which the cue appeared.

The third question addressed in this experiment was whether the spatial extent of attention can be varied in size from trial to trial, depending on the size of the exogenous cue, and if so, what effect this would have on stimulus discrimination. The results from both the accuracy and response time data indicated that subjects were able to allocate attention to a location cued by either a small or large cue; performance was enhanced when the cue was valid over when the cue was invalid regardless of the size of the area cued. When a small cue was used to orient attention, however, the difference in performance on valid versus invalid trials tended to be greater than when large cues were used. This was due both to larger facilitation at the cued location and larger inhibition at uncued locations in relation to the neutral baseline condition.

Experiment 2

Experiment 2 replicated Experiment 1 through the use of response time as the primary dependent measure. This replication was thought necessary to allow comparison with prior studies that explored covert visual orienting, a majority of which used response latency rather than accuracy. To improve response accuracy across conditions to a near-ceiling level and thus make the response time measure more interpretable, the pattern mask following presentation of the target was not used. Note that even without the pattern mask, phosphor persistance could not increase the effective target duration because the stimuli were displayed black on white (i.e., in reverse video).

Method

Subjects. Twelve University of Alberta undergraduate students participated for credit toward their introductory psychology class. All subjects had normal or corrected-to-normal vision. None of the subjects had participated in Experiment 1.

Apparatus, stimuli, and procedure. The apparatus, stimuli, and procedure were identical to those used in Experiment 1 except that no pattern mask appeared following presentation of the target. Instead, the fixation display reappeared until a response was made. At that time, the mask appeared as the between-trial display indicating the eight possible target locations (as had been the case in Experiment 1).

Results

Analyses were conducted on the mean percentage of correct responses and mean response times for correct responses. As

expected, overall accuracy was nearly perfect (98%) and did not differ by condition, $F < 1$. The primary dependent measure for this experiment was therefore response time, as intended.

Response time. Response time analyses included correct trials only. In addition, outlier response times less than 100 ms, greater than 3,000 ms, or more than three standard deviations from the cell mean for that condition and that subject were discarded to reduce variability. A total of 2% of the data were categorized as outliers.

Once again, there was a reliable overall effect of cue validity, $F(1, 11) = 19.3$, $MS_e = 1,088$, $p < .005$. Mean response time was 446 ms and 476 ms for valid and invalid trials, respectively.

Figure 3 presents the response time data as a function of cue size and cue validity, with invalid trials shown as a function of hemifield location (excluding the within-quadrant invalid and neutral trials). For the invalid trials, neither the effect of cue size nor hemifield location was significant, $F(1, 11) = 3.16$, $MS_e = 915$, $p > .10$, and $F < 1$, respectively, nor did these variables interact, $F < 1$.

As can be seen in Table 2, performance in the within-quadrant invalid condition was significantly poorer than performance in the small-valid-cue condition, $F(1, 11) = 29.0$, $MS_e = 335$, $p < .001$. In addition, in contrast to Experiment 1, performance in the within-quadrant invalid condition was better than performance in the small-invalid-cue condition, $F(1, 11) = 7.61$, $MS_e = 492$, $p < .05$.

To examine whether small cues facilitated performance more than large cues, a separate analysis was conducted over cue size and cue validity by collapsing over hemifield location and ignoring the within-quadrant invalid and neutral conditions. In contrast to Experiment 1, the Cue Size × Cue
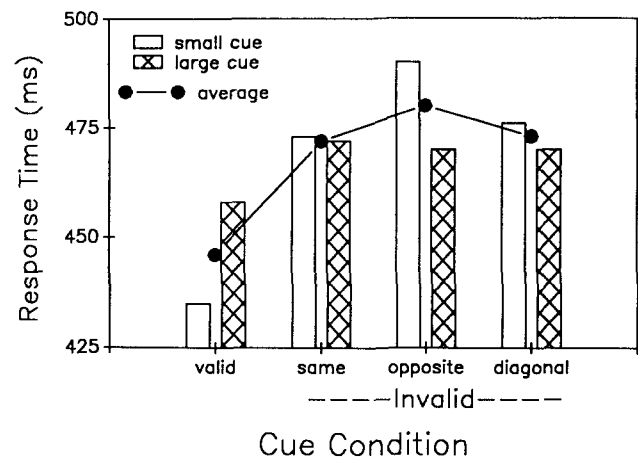

Figure 3. Mean response time as a function of cue validity (by location) and cue size for Experiment 2. (Performance for neutral trials and within-quadrant invalid trials is not shown. *Same* denotes the quadrant in the same lateral hemifield but opposite vertical hemifield, *opposite* denotes the quadrant in the opposite lateral hemifield but same vertical hemifield, and *diagonal* denotes the quadrant in the opposite lateral and vertical hemifields.)

Table 2
Mean Response Time for Trials in Experiment 2

Condition	Mean performance (in ms)	Performance versus neutral condition (in ms)
Small valid cue	435	27*
Small invalid cue	480	−18
Within-quadrant invalid	464	−2
Large valid cue	458	4
Large invalid cue	471	−9
Neutral cue	462	—

Note. Performance in the small- and large-invalid-cue trials has been collapsed over hemifield location. Negative numbers indicate poorer performance in comparison to the neutral condition.
* $p < .05$.

Validity interaction reached significance, $F(1, 11) = 22.4$, $MS_e = 294$, $p < .001$. The interaction again appears to be due to a larger difference in performance between the valid and invalid conditions when the cues were small compared with when they were large. Finally, there was a main effect of cue size, $F(1, 11) = 5.35$, $MS_e = 157$, $p < .05$, with performance in the small-cue condition slightly faster than performance in the large-cue condition.

Table 2 also shows the response time costs and benefits associated with each of the other conditions in relation to the neutral condition. These data again showed performance in the neutral condition to be about intermediate between performance in the valid and invalid conditions.

Discussion

The pattern of results found in Experiment 2 through the use of response time as the dependent measure generally replicated the main findings of Experiment 1, in which accuracy was the primary dependent measure. First, there was once again a robust effect of attentional orienting on stimulus discrimination in an otherwise blank field. Second, no differences were found for performance in the invalid conditions as a function of the quadrant in which the target appeared in relation to the quadrant cued, and performance for targets that appeared in the cued quadrant but at the uncued location was poorer than performance for targets that appeared at the cued location. Neither of these latter effects is consistent with the hypothesis that attention is directed to either a hemifield or quadrant (Hughes & Zimba, 1985, 1987). Third, small cues again affected performance more than did large cues. Potential explanations for the reduced effect of the large cues are deferred until the General Discussion section.

An additional interesting result that was not found in Experiment 1 was found in Experiment 2: Performance for targets that appeared in the cued quadrant but at the uncued location was facilitated over performance for targets that appeared in an uncued quadrant. This result suggests that the attentional effect of orienting to an exogenous cue may fall off gradually with distance from the cued location.

Experiment 3

In Experiments 1 and 2, performance in the within-quadrant invalid condition was found to be worse than perform-

ance in the small-valid-cue condition and either equal to (Experiment 1) performance in the small-invalid-cue condition, or better (Experiment 2). This pattern of results may be expected because of differences in the relative proportions of different types of trials. In particular, there were 48 small valid and 48 small invalid trials per subject, whereas there were only 32 within-quadrant invalid trials per subject. Thus, given a small cue, the probability of the target appearing at the cued location was .375, whereas the probability of the target appearing at the uncued location within the quadrant was .25. Fewer trials in the within-quadrant invalid condition might have led to poorer performance because of expectancy or practice effects. An underestimate of performance in the within-quadrant invalid condition biases the interpretation of the results toward the hypothesis that attention is directed to a specific location rather than to a visual quadrant. To determine whether the results found regarding the within-quadrant invalid condition in Experiments 1 and 2 were due to probability differences, in Experiment 3 I used an equal number of trials (48) in the small valid, large valid, small invalid, large invalid, and within-quadrant invalid conditions. Therefore, the probability of the target appearing at the cued location and at the within-quadrant uncued location given a small cue was .33.

A second purpose of Experiment 3 was to determine whether the advantage found for targets in the within-quadrant invalid condition in comparison to the small invalid condition observed in Experiment 2 was reliable and could be found for response accuracy. In Experiment 3 the duration of the target was reduced from 67 to 50 ms in an attempt to increase the benefits of orienting to a validly cued location and therefore to increase differences across the valid and invalid conditions. The decrease in target duration also further ensured that the effects observed in the previous experiments could not be attributed to overt eye movements.

Method

Subjects. Twelve University of Alberta undergraduate students participated for credit toward their introductory psychology class. All subjects had normal or corrected-to-normal vision. None of the subjects had participated in Experiments 1 or 2.

Apparatus, stimuli, and procedure. The apparatus, stimuli, and procedure were identical to those used in Experiment 1 with the following exceptions: (a) The target duration was reduced to 50 ms; (b) the neutral condition was not used; (c) three replications of the within-quadrant invalid condition were shown to each subject. There were thus 48 trials in each of five conditions (small valid, small invalid, large valid, large invalid, and within-quadrant invalid), or 240 trials. Given a small location cue, the target appeared in the cued location with .333 probability, at the other location in the quadrant with .333 probability, and in one of the other three quadrants with .333 probability (.055 probability for each of the other six locations). Thus, given a small cue, the target appeared at the cued location and at the within-quadrant uncued location with equal probability. Given a large location cue, the target appeared in the cued quadrant with .50 probability (.25 at each of the two locations within the quadrant). When the target did not appear in the cued quadrant, it appeared in one of the other three quadrants with .50 probability (.833 probability for each of the other six locations). Thus, the small cue was slightly

more predictive of the quadrant within which the target appeared (.666 vs. .50).

Results

Analyses were conducted on the mean percentage of correct responses and mean response times for correct responses.

Percentage correct. As found in Experiment 1, there was a significant main effect of cue validity. Mean accuracy rate was .87 when the target appeared at the cued location and .65 when the cue appeared in another quadrant, $F(1, 11) = 63.9$, $MS_e = 0.0182$, $p < .001$. As expected, this effect was larger than that observed in Experiment 1.

Figure 4 shows the mean accuracy rates as a function of cue size and cue validity (excluding the within-quadrant invalid condition), with invalid trials shown as a function of hemifield location in relation to the cue. For the invalid trials, there was a marginal effect of hemifield location, $F(2, 22) = 3.40$, $MS_e = 0.0289$, $.05 < p < .10$. As can be seen in Figure 4, this marginal effect was due to poorer performance in the diagonal condition. There was no indication of a difference between the same lateral and opposite lateral hemifield conditions, $F < 1$. There was also a marginal effect of cue size, $F(1, 11) = 3.25$, $MS_e = 0.0209$, $.05 < p < .10$. As can be seen in Figure 4, this marginal effect was due to poorer performance for the invalid trials given a small cue. Finally, there was no interaction between hemifield location and cue size, $F < 1$.

Of particular interest in this experiment was the within-quadrant invalid condition in relation to the small valid and small invalid conditions. As can be seen in Table 3, performance in the within-quadrant invalid condition was significantly poorer than performance in the small-valid-cue condition, $F(1, 11) = 6.66$, $MS_e = 0.0168$, $p < .05$, which replicated Experiments 1 and 2. In addition, performance in
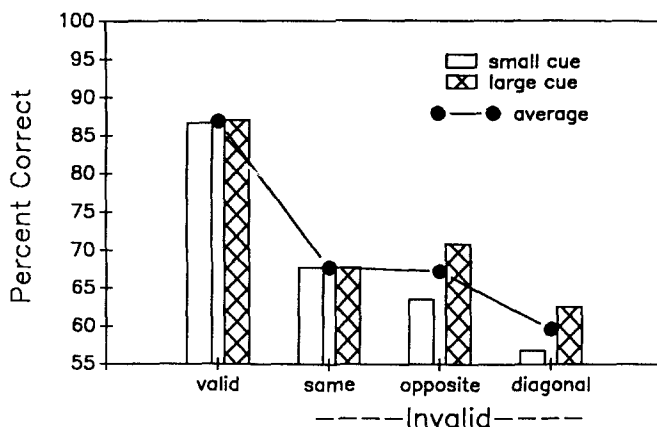
the within-quadrant invalid condition also differed significantly from performance in the small-invalid-cue condition, $F(1, 11) = 58.2$, $MS_e = 0.0042$, $p < .001$, which replicated Experiment 2. Taken together, these results indicate that performance in the within-quadrant invalid condition is intermediate between performance in the small-valid- and small-invalid-cue conditions.

The current experiment allowed further examination of whether small cues facilitate performance more than large cues. The experiment was treated as a 2 × 2 factorial design (cue size and cue validity) and the within-quadrant invalid condition was ignored: The Cue Size × Cue Validity was not significant, $F(1, 11) = 1.21$, $MS_e = 0.0078$, $p > .25$. As can be seen in Table 3, however, there was again a tendency toward a greater difference between the valid and invalid trials when the cue was small compared with when the cue was large.

Response time. Response time analyses included only correct trials. In addition, outlier response times less than 100 ms, greater than 3,000 ms, or more than three standard deviations from the cell mean for that condition and that subject were discarded to reduce variability. A total of 3% of the data were categorized as outliers.

As in the accuracy data, there was a reliable effect of cue validity, $F(1, 11) = 51.4$, $MS_e = 15,266$, $p < .001$. Mean response time was 646 and 827 ms for valid and invalid trials, respectively.

Figure 5 shows the response time data as a function of cue size and cue validity (ignoring the within-quadrant invalid condition), with invalid trials shown as a function of target hemifield location. For the invalid trials, neither the effect of cue size nor hemifield location was significant: $F(1, 11) = 1.68$, $MS_e = 18,300$, $p > .20$, and $F(2, 22) = 1.00$, respectively. These two variables did not interact, $F(2, 22) = 1.56$, $MS_e = 33,916$, $p > .20$.

The response time data for the within-quadrant invalid condition also mirrored the accuracy data. As can be seen in Table 3, performance in the within-quadrant invalid condition was significantly poorer than performance in the small-valid-cue condition, $F(1, 11) = 19.3$, $MS_e = 9.230$, $p < .005$; it also differed significantly from performance in the small-invalid-cue condition, $F(1, 11) = 22.3$, $MS_e = 4,460$, $p < .001$.

Finally, in the analysis examining cue size and cue validity collapsed over hemifield (excluding the within-quadrant invalid condition), the Cue Size × Cue Validity interaction was significant, $F(1, 11) = 6.26$, $MS_e = 3,923$, $p < .05$. Again, this effect occurred because small cues produce more of a difference between valid and invalid trials than do large cues.

Figure 4. Mean response accuracy as a function of cue validity (by location) and cue size for Experiment 3. (Performance for within-quadrant invalid trials is not shown. *Same* denotes the quadrant in the same lateral hemifield but opposite vertical hemifield, *opposite* denotes the quadrant in the opposite lateral hemifield but same vertical hemifield, and *diagonal* denotes the quadrant in the opposite lateral and vertical hemifields.)

Discussion

The results of this experiment generally replicated the main findings of Experiments 1 and 2. First, robust effects of exogenous orienting on stimulus discrimination in an otherwise blank field were found. Second, no advantage was found for targets appearing in the same lateral hemifield as the cue, and targets that appeared at the specific location cued within a quadrant were facilitated in comparison to targets appearing

Table 3

Mean Accuracy (Percentage Correct) and Response Times (RT) for Trials in Experiment 3

Condition	Mean performance	
	% Correct	RT (in ms)
Small valid cue	87	628
Small invalid cue	63	841
Within-quadrant invalid	77	750
Large valid cue	87	663
Large invalid cue	67	812

Note. Performance in the small- and large-invalid-cue trials has been collapsed over hemifield location.

at another location in the same cued quadrant. This latter result was found even though given a small cue the probability of the target appearing at the within-quadrant invalid location was equated with the probability of the target appearing at the cued location, which indicates that the specific location advantage observed in Experiments 1 and 2 was not due to the probability differences in those experiments. Third, small cues produced a greater difference in performance between valid and invalid trials than did large cues.

Finally, an advantage in both accuracy and response time was found for targets appearing at the uncued location within the cued quadrant over targets appearing within an uncued quadrant. This result was also found in Experiment 2 and is consistent with the view that the effect of attentional orienting to an exogenous cue falls off gradually with distance from the cued location.

Experiment 4

In Experiments 1–3, performance in the large-cue condition was generally less affected by cue validity than was perform-
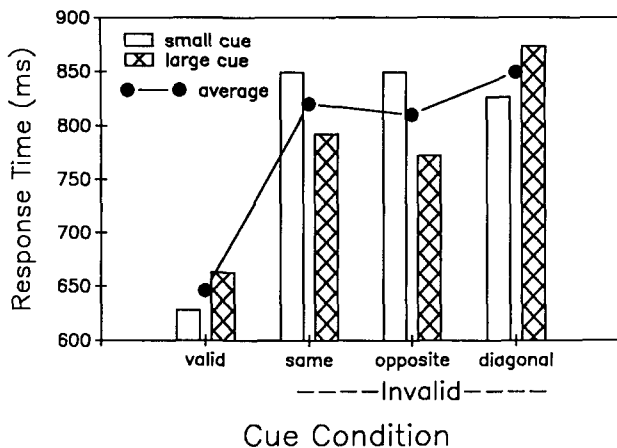

Figure 5. Mean response time as a function of cue validity (by location) and cue size for Experiment 3. (Performance for within-quadrant invalid trials is not shown. *Same* denotes the quadrant in the same lateral hemifield but opposite vertical hemifield, *opposite* denotes the quadrant in the opposite lateral hemifield but same vertical hemifield, and *diagonal* denotes the quadrant in the opposite lateral and vertical hemifields.)

ance in the small-cue condition. This difference may indicate that the large cues were less effective at drawing attention, perhaps because small cues were more predictive of the target quadrant than were large cues (.625 vs. .50 in Experiments 1 and 2, .666 vs. .50 in Experiment 3). This difference in predictability occurred because the total number of trials in the small valid and within-quadrant invalid conditions together always exceeded the number of trials in the large valid condition. It therefore seemed appropriate to determine whether a difference between small- and large-cue conditions would be found if predictability in each case were equated. In Experiment 4 the within-quadrant invalid condition was dropped and 48 trials each of the small valid, large valid, small invalid, large invalid, and neutral conditions were used. With this design, the small and large cues were equally predictive of the target quadrant (.50), though given that the target did appear in the cued quadrant, the small cue perfectly predicted the specific location within the quadrant, whereas the large cue gave no information with regards to the specific location within the quadrant. Note also that the probability of the target appearing in one of the six locations beyond the quadrant within which the cue appeared was equated given either a small or large cue. As in Experiment 3, target display duration was 50 ms.

Method

Subjects. Twelve University of Alberta undergraduate students participated for credit toward their introductory psychology class. All subjects had normal or corrected-to-normal vision. None of the subjects had participated in Experiments 1, 2, or 3.

Apparatus, stimuli, and procedure. The apparatus, stimuli, and procedure were identical to those used in Experiment 3 with the following exceptions: (a) The within-quadrant invalid condition was not used, and (b) the neutral condition was reinstated as described in Experiments 1 and 2. There were thus 48 trials of each of five conditions (small valid, small invalid, large valid, large invalid, and neutral), or 240 trials. Given a small location cue, the target appeared in the cued location with .50 probability, at the other location in the quadrant with 0 probability, and in one of the other three quadrants with .50 probability (.0833 probability for each of the other six locations). Given a large location cue, the target appeared in the cued quadrant with .50 probability (.25 at each of the two locations within the quadrant). When the target did not appear in the cued quadrant, it appeared in one of the other three quadrants with .50 probability (.0833 probability for each of the other six locations). Thus, the small and large cues were equally predictive of the region within which the target appeared though that region was larger (it included two locations) in the case of the large cue and smaller (it included only one location) in the case of the small cue.

Results

Analyses were conducted on the mean percentage of correct trials and mean response times for correct responses.

Percentage correct. Mean accuracy rate was .89 when the target appeared at the cued location, and .70 when the cue appeared in another quadrant, $F(1, 11) = 35.5, MS_e = 0.0245, p < .001$.

Figure 6 shows the mean accuracy rates as a function of cue size and cue validity, with invalid trials shown as a
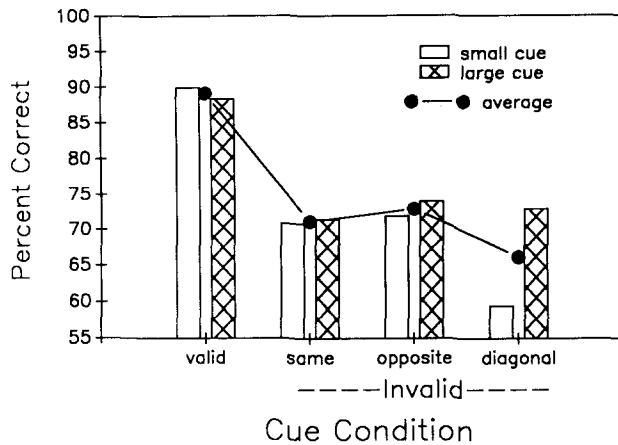
Figure 6. Mean response accuracy as a function of cue validity (by location) and cue size for Experiment 4. (Performance for neutral trials is not shown. *Same* denotes the quadrant in the same lateral hemifield but opposite vertical hemifield, *opposite* denotes the quadrant in the opposite lateral hemifield but same vertical hemifield, and *diagonal* denotes the quadrant in the opposite lateral and vertical hemifields.)

Table 4

Mean Accuracy and Response Times (RT) for Trials in Experiment 4

Condition	Mean performance		Performance versus neutral condition	
	% Correct	RT (in ms)	% Correct	RT (in ms)
Small valid cue	90	654	6**	145***
Small invalid cue	67	878	−17***	−79**
Large valid cue	88	729	4*	70***
Large invalid cue	73	840	−11***	−41**
Neutral cue	84	799	—	—

Note. Performance in the small- and large-invalid-cue trials has been collapsed over hemifield location. Negative numbers indicate poorer performance in comparison to the neutral condition.
*$p < .10$.   **$p < .05$.   ***$p < .01$.

function of hemifield location in relation to the cue (the neutral condition was ignored in this analysis). For the invalid trials, there were no significant main effects of hemifield location, $F(2, 22) = 1.82$, $MS_e = 0.0324$, $p > .15$, or of cue size, $F(1, 11) = 2.74$, $MS_e = 0.0380$, $p > .10$. The interaction between these two variables was significant, $F(2, 22) = 5.32$, $MS_e = 0.0114$, $p < .05$. As can be seen in Figure 6, this interaction was due to the poorer performance in the small-cue diagonal condition. When the diagonal condition was removed from the analysis, the interaction disappeared, $F < 1$.

The main issue explored in this experiment was whether the same pattern of data observed in Experiments 1–3 for the small versus large cues would also be observed if the number of valid and invalid trials for the two cue sizes were equated. To investigate this issue, a 2 × 2 variable analysis was conducted with cue size and cue validity (with invalid trials collapsed over hemifield) as variables and the neutral condition excluded. Consistent with the pattern observed in the first three experiments, the Cue Size × Cue Validity interaction was marginally significant, $F(1, 11) = 3.28$, $MS_e = 0.0091$, $.05 < p < .10$. Again, as can be seen in Table 4, the marginal interaction occurred because the difference between valid and invalid trials when the cue was large was not as great as when the cue was small. The main effect of cue size was not significant, $F(1, 11) = 1.45$, $MS_e = 0.0058$, $p > .20$.

Table 4 includes a comparison of the costs and benefits associated with each of the other conditions in relation to the neutral condition. Performance in the neutral condition was clearly intermediate between performance in the valid and invalid conditions.

Response time. Response time analyses included correct trials only. In addition, outlier response times less than 100 ms, greater than 3,000 ms, or more than three standard deviations from the cell mean for that condition and that

subject were discarded to reduce variability. A total of 4% of the data were categorized as outliers.

There was a reliable effect of cue validity, $F(1, 11) = 51.0$, $MS_e = 13,175$, $p < .001$. Mean response time was 692 ms and 859 ms for valid and invalid trials, respectively.

Figure 7 shows the response time data as a function of cue size and cue validity (excluding the neutral condition), with invalid trials shown as a function of target hemifield location. For the invalid trials, the main effect of cue size was not significant, $F(1, 11) = 2.01$, $MS_e = 25,713$, $p > .15$. The main effect of hemifield location reached significance, $F(2, 22) = 3.46$, $MS_e = 18,072$, $p < .05$, although the two variables did not interact, $F(2, 22) = 1.18$, $MS_e = 45,455$, $p > .30$. The significant effect of hemifield location was due to the overall poorer performance in the diagonal condition; the difference between the same and opposite hemifield locations was not significant, $F < 1$.

In the analysis in which cue size and cue validity collapsed over hemifield (and excluding the neutral condition) were examined, the Cue Size × Cue Validity interaction was significant, $F(1, 11) = 10.8$, $MS_e = 7,036$, $p < .01$. As shown in Table 4, the difference in performance between valid and invalid conditions was again larger when the cues were small compared with when the cues were large. The main effect of cue size was not significant, $F(1, 11) = 1.17$, $MS_e = 6,889$, $p > .30$.

Table 4 also shows the response time costs and benefits associated with each of the other conditions in relation to the neutral condition. These data mirrored the accuracy data and again showed performance in the neutral condition to be intermediate between performance in the valid and invalid conditions.

Discussion

The main purpose of Experiment 4 was to determine whether the greater differences in performance between valid and invalid trials observed with small versus large cues in Experiments 1–3 were because in those experiments the small cues were more predictive of the area within which the target appeared. Contrary to this hypothesis, the same pattern was found here when the small and large cues were equally pre-
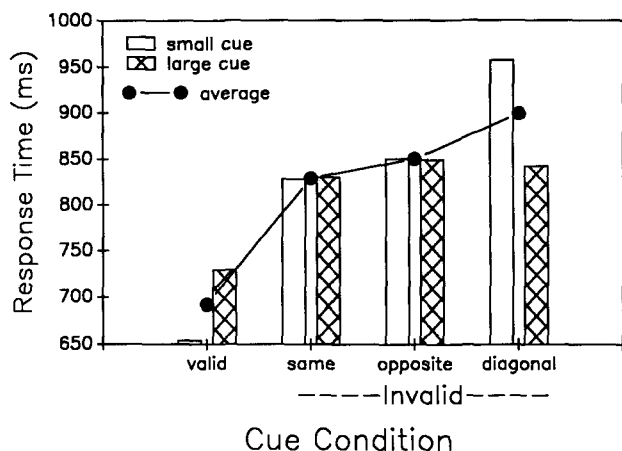
Figure 7. Mean response time as a function of cue validity (by location) and cue size for Experiment 4. (Performance for neutral trials is not shown. *Same* denotes the quadrant in the same lateral hemifield but opposite vertical hemifield, *opposite* denotes the quadrant in the opposite lateral hemifield but same vertical hemifield, and *diagonal* denotes the quadrant in the opposite lateral and vertical hemifields.)

dictive of the target area, though of course in the case of the large cue this area was larger.

Experiment 5

In Experiments 1–4, the assumption has been that performance differences across cuing conditions were due to exogenous rather than endogenous attentional mechanisms. Nevertheless in each experiment the probability that the target would appear at a particular location differed as a function of the cue. For example, in each of the experiments that included the within-quadrant invalid condition, the target was more likely to appear at the within-quadrant invalid location than at any of the other invalid locations. If subjects were sensitive to these differences and used them to generate expectations about likely target locations, then performance across conditions in each experiment may have been at least partly due to endogenous attentional mechanisms. Given that the purpose of the present study was to investigate the influence of the manipulated variables on the operation of the exogenous system alone, I conducted a final experiment to determine whether the same pattern of results would be found if the probability of the target appearing at each possible location were equated across cue type and cue size.

In Experiment 5, the target could appear at one of four possible locations in each trial: the two locations within the cued quadrant and the two locations within the quadrant diagonally opposite the cued quadrant. Given either a small or large cue, the target could appear at each of the four locations with equal probability (.25), thus making the cues completely uninformative. If the same general pattern of results regarding cue size and cue validity was found in this experiment as was found in the prior experiments, then the assumption that the effects observed in those experiments

were indeed due to the operation of exogenous orienting would be supported.

Method

Subjects. Twelve University of Alberta undergraduate students participated for credit toward their introductory psychology class. All subjects had normal or corrected-to-normal vision. None of the subjects had participated in any of the prior experiments.

Apparatus, stimuli, and procedure. The apparatus, stimuli, and procedure were identical to those used in Experiment 3 with the following exceptions: (a) For outside-quadrant invalid trials, the target always appeared at one of the two locations in the quadrant diagonally opposite the cued quadrant, and (b) the cues were totally uninformative about the location of the target—on each trial, the target was equally likely to appear at each of four possible locations regardless of the location of the cue. Given a small cue, there were 32 trials when the target appeared at the cued location (small-valid-cue condition), 32 trials when the target appeared at the uncued location within the quadrant (within-quadrant invalid condition), and 64 trials when the target appeared in the quadrant diagonal to the cued quadrant (32 trials at each of the two locations within that quadrant: small-invalid-cue condition). Given a large cue, there were 64 trials when the target appeared at one of the two locations within the quadrant (32 at each location: large-valid-cue condition) and 64 trials when the target appeared in the quadrant diagonal to the cued quadrant (32 trials at each of the two locations: large-invalid-cue condition). Thus, there were 256 trials. The probabilities were as follows: Given a small location cue, the target appeared in the cued location with .25 probability, at the other location in the quadrant with .25 probability, and in the diagonal quadrant with .50 probability (.25 probability for each of the two locations). Given a large location cue, the target appeared in the cued quadrant with .50 probability (.25 at each of the two locations within the quadrant). When the target did not appear in the cued quadrant, it appeared in the diagonal quadrant with .50 probability (.25 probability for each of the two locations).

Results

Analyses were conducted on the mean percentage of correct trials and mean response times for correct responses.

Percentage correct. Mean accuracy rate was .87 when the target appeared at the cued location and .64 when the cue appeared in another quadrant, $F(1, 11) = 85.7, MS_e = 0.0137, p < .001$.

Table 5 shows the mean accuracy rates in each of the cue conditions. As has generally been found in each of the experiments reported previously, performance in the within-quadrant invalid condition was significantly poorer than performance in the small-valid-cue condition, $F(1, 11) = 20.9, MS_e = 0.0128, p < .005$, and was significantly better than performance in the small-invalid-cue condition, $F(1, 11) = 12.5, MS_e = 0.0135, p < .005$.

A 2 × 2 analysis was conducted with cue size and cue validity as variables and the within-quadrant invalid condition excluded. Consistent with the pattern observed in the first four experiments, the difference between valid and invalid trials when the cue was large was not as great as when the cue was small, $F(1, 11) = 7.95, MS_e = 0.0064, p < .05$, for the

Table 5

Mean Accuracy and Response Times (RT) for Trials in Experiment 5

Condition	Mean performance	
	% Correct	RT (in ms)
Small valid cue	90	700
Small invalid cue	63	873
Within-quadrant invalid	75	815
Large valid cue	84	749
Large invalid cue	66	896

Cue Size × Cue Validity interaction. The main effect of cue size was not significant, $F < 1$.

Response time. Response time analyses included correct trials only. In addition, outlier response times less than 100 ms, greater than 3,000 ms, or more than three standard deviations from the cell mean for that condition and that subject were discarded to reduce variability. A total of 2% of the data were categorized as outliers.

The response time data in each of the cue conditions are shown in Table 5. There was a reliable effect of cue validity, $F(1, 11) = 27.1$, $MS_e = 22,679$, $p < .001$. Mean response time was 724 ms and 884 ms for valid and invalid trials, respectively.

As found in the response accuracy data, performance in the within-quadrant invalid condition was significantly poorer than performance in the small-valid-cue condition, $F(1, 11) = 11.3$, $MS_e = 14,192$, $p < .01$, and significantly better than performance in the small-invalid-cue condition, $F(1, 11) = 6.10$, $MS_e = 6,570$, $p < .05$.

In the analysis that examined cue size and cue validity (and excluded the within-quadrant invalid condition), the Cue Size × Cue Validity interaction was not significant, $F < 1$. The main effect of cue size was marginally significant, $F(1, 11) = 3.47$, $MS_e = 8,965$, $.05 < p < .10$.

Discussion

The main issue addressed in Experiment 5 was whether effects similar to those found in Experiments 1–4 with regard to cue size and cue validity may be observed given cues that were uninformative about the likely location of the target. To investigate this issue, targets appeared with equal probability at each of four locations following either a large or a small cue. There were three main findings. First, the effect of attentional orienting was of similar magnitude to that observed in the previous experiments, even though the cues were uninformative. Second, performance in the within-quadrant invalid condition was poorer than performance in the small-valid-cue condition and better than performance in the small-invalid-cue condition. The finding that the latter effect occurred even though the probability of the target appearing at the within-quadrant invalid location was the same as its appearance at each of the outside-quadrant invalid locations indicates that the advantage for the within-quadrant target was not due to differential subject expectancies. Third, the small cues again tended to produce larger overall orienting

effects than did the large cues. Taken together, these results support the view that the patterns of data observed in Experiments 1–4 were due to effects of the manipulated variables (cue size and cue validity) on the exogenous attentional system and not due to subject expectancies (the endogenous system).

General Discussion

In the present study I investigated the covert allocation of visual–spatial attention following an exogenous cue. More specifically, three main questions were addressed. First, does covert orienting lead to performance differences at cued and uncued locations when the task comprises target discrimination in an otherwise blank field? Second, must attention be allocated to large regions of the visual field such as a hemifield or visual quadrant following an exogenous cue, or can attention be allocated to more limited locations? Third, can a large exogenous cue induce the orienting of a wider focus of attention than a small exogenous cue, and if so, what effect does this have on stimulus discrimination at cued and uncued locations?

Beginning with the first question, the results of the experiments reported in this article clearly demonstrated that stimulus discrimination in an otherwise empty field was enhanced following an exogenous cue. This enhancement in performance was seen in both response accuracy and response latency. The small effects observed in prior studies may have been due to the specific characteristics of the paradigms used. For example, Posner (1980) used a large peripheral square to cue attention; given the results of the experiments reported here, the large cue may have caused attention to be spread over too large a region to produce robust effects. In addition, Posner (1980) used a cue-target stimulus onset asynchrony likely to involve the endogenous rather than the exogenous attentional system. The exogenous system may be more intimately involved with determining the identity of a stimulus. The notion that exogenous orienting facilitates stimulus discrimination more than does endogenous orienting is consistent with the claim that the exogenous system is more involved with feature combination (Briand & Klein, 1987). Finally, in the van der Heijden et al. (1985) study, only facilitation effects were examined rather than facilitation and inhibition effects. Clearly, the effects of cuing are most obvious when validly and invalidly cued locations are compared. When the experimental paradigm allows observation of facilitation effects alone, the ability to see an effect of cuing is much more dependent on the neutral condition chosen (Jonides & Mack, 1984).

The second question addressed in the present study concerned whether attention following an exogenous cue is oriented to a specific location within a visual quadrant rather than to the entire quadrant or perhaps the entire hemifield. The results were consistent with the hypothesis that attention is oriented to the specifically cued location. First, there was no performance advantage for targets following invalid cues when they appeared in the same lateral (or vertical) hemifield as the cue compared with when they appeared in the opposite hemifield. This result was found in all four experiments in which it was tested (Experiments 1–4), and it provides evi-

dence against the lateral hemifield version of a general location hypothesis (Hughes & Zimba, 1985). Second, when small cues were used, targets appearing in the same quadrant as a small cue but at a different noncued location produced consistently poorer performance than targets that appeared at the cued location. This result was found in all four experiments in which it was tested (Experiments 1, 2, 3, and 5), and it provides strong evidence against the quadrant version of the general location hypothesis (Hughes & Zimba, 1987). Instead, this result supports the conclusion that attention can be oriented specifically to the cued location. Also consistent with this conclusion are results recently reported by Klein and McCormick (1989; McCormick & Klein, in press) which show that attention can be oriented to a specific location in an endogenous cuing paradigm as well.

The general pattern of data across the four experiments was as follows: Best discrimination performance was found following a valid cue; performance became progressively worse for targets in the same quadrant but at the uncued location, followed by performance in the two adjacent quadrants, with possibly the worst performance in the diagonal quadrant (Experiment 4). I discuss several potential explanations for this pattern of results in the following section.

Exogenously Induced Changes in the Spatial Extent of the Attended Region

The final issue examined in this study was the deployment of attention following a small versus a large exogenous cue. In the present study, cue size and cue validity were consistently found to interact. There are three possible explanations for this interaction: (a) Large cues attract attention to only one of the two cued locations; (b) large cues attract attention less readily; (c) large cues cause attention to focus over a greater area.

According to the first view, when a large cue was shown subjects oriented a narrow focus of attention (similar to the focus of attention generated to a small cue) to one of the two cued locations in the quadrant. Such orienting might conceivably take place if the two simultaneously displayed cues comprised two separate transient events rather than a single transient event. If attention were oriented to one of the cues on each large-cue trial, then reduced performance is expected in the large-valid-cue condition compared with the small-valid-cue condition because the narrow focus in the large-cue condition is sometimes on the wrong specific location. The simplest model instantiating this assumption is that if attention were directed to the correct location within the quadrant performance would be the same as in the small valid-cue condition, and if attention were directed to the wrong location within the quadrant performance would be the same as in the within-quadrant invalid condition. Given this model, we expect that attention is directed to the correct specific location on 50% of the trials and to the incorrect location on the remaining 50% of the trials. The predicted accuracy and response times on this model for Experiments 1, 2, 3, and 5 (in which the within-quadrant invalid condition was used), along with the actual accuracy and response times, are shown in Table 6. Although the estimates are not unreasonable, they

Table 6

Predicted and Observed Performance in the Large-Valid-Cue Condition for Experiments 1–3 and 5

Experiment	% Correct		Response time (in ms)	
	Predicted	Observed	Predicted	Observed
1	88	91	639	621
2	—	—	451	458
3	82	87	687	663
5	82	84	758	749
M	84	87	634	623

tend to underestimate the observed performance. To test the fit more formally, an analysis of variance was conducted with experiment as a between-subjects variable and performance (predicted vs. observed) as a within-subjects variable. For the accuracy measure, the difference between predicted and observed performance was significant, $F(1, 33) = 5.76$, $MS_e = 0.006$, $p < .05$. For response time, predicted and observed performance did not differ, $F(1, 44) = 1.61$, $MS_e = 3,586$, $p > .20$, though it is clear that the direction of the response time difference is consistent with the accuracy data.

A further prediction can be derived from this model: Given that invalid trials involve the same type of discrimination process following either small or large cues (the process involved when a small focus of attention is allocated to the wrong location), we expect no difference on invalid trials outside the cued quadrant given a large or small cue. Contrary to this prediction, performance in the large invalid condition was generally better than performance in the small invalid condition across experiments, as summarized in Table 7. The difference across experiments was significant for the accuracy measure, $F(1, 44) = 9.16$, $MS_e = 0.009$, $p < .005$, but not significant for the latency measure, $F < 1$. In summary, the hypothesis that the large cues induce orienting to one of the two locations in the quadrant is not supported by the observed performance level in the valid trials predicted by a simple instantiation of this hypothesis or the performance level in the invalid trials predicted by this hypothesis.

Second, the small cues may have been better able to attract an orienting response than were the large cues. This hypothesis naturally explains why performance tended both to be better following valid small cues and worse following invalid small cues compared with the same large-cue conditions. Neverthe-

Table 7

Differences (Large Invalid Minus Small Invalid Trials) in Experiments 1–5

Experiment	% Correct	Response time (in ms)
1	4	+18
2	—	−9
3	4	−29
4	6	−38
5	3	+23
M	4	−8

less, such a hypothesis would also have to explain how attention is allocated to the cued locations following a large cue on those trials when attention is successfully attracted. In other words, given that a large cue produces some effect in relation to a neutral cue, an explanation is still needed for how attention is oriented following a large cue. As has already been shown, performance was better than expected on the basis of the hypothesis that attention is devoted to one of the two cued locations on each large-cue trial. Adding the assumption that attention is not always oriented following a large cue to the assumption that attention is oriented to one of the cued locations following a large cue only leads to a greater difference between predicted and observed performance on this model. The view that attention was less well oriented following a large cue still needs the assumption that attention following a large cue is allocated simultaneously to both cued locations.

A final potential explanation for the poorer performance following large versus small valid cues is that a small cue induced a narrow focus of attention to a specific location, whereas a large cue induced a broader focus of attention to a region of space that encompassed both cued locations within the quadrant. The two models outlined in the Introduction, the zoom-lens and gradient models, both include such an assumption, and the data will be discussed in relation to these models next.

The zoom-lens model. According to the zoom-lens model, because a wider distribution of attention leaves less resolving power at attended locations (C. W. Eriksen & St. James, 1986; C. W. Eriksen & Yeh, 1985), performance following large cues is expected to be poorer than following small cues, as observed. Why, however, should there be a difference between the small- and large-cue conditions given an invalid cue? If we assume that attention must reorient following allocation to the wrong location, then to account for the data with the zoom-lens model we must also postulate that less time is required to reorient attention to the target location when attention has initially been distributed over a greater area. Two possible mechanisms may account for this differential reorienting time. First, if attention is reoriented by moving the focus through an analogue representation of space (Shulman, Remington, & McLean, 1979; Tsal, 1983), then the "leading edge" of the focus would be expected to reach the new location sooner when the focus was larger. Nevertheless, such an analogue movement of attention is at odds with recent evidence which indicates that the time needed to orient attention does not vary with spatial distance (Murphy & Eriksen, 1987; Remington & Pierce, 1984; Yantis, 1988) and is inconsistent with the current formulation of the zoom-lens model (e.g., C. W. Eriksen & St. James, 1986; C. W. Eriksen & Webb, 1989). Second, it could be assumed that when the focus of attention is distributed over a greater area, then it is easier to disengage attention from that area so that reorienting is more rapid. Although this assumption clearly predicts that there will be greater cost for orienting to a small area than a larger area when the cue is invalid, it is not particularly motivated beyond its ability to account for the current data set.

If the time to reorienting attention is invariant over spatial distance, as the zoom-lens model assumes, then it is not clear

how the model could account for the finding that given a small cue, performance in the within-quadrant invalid condition was consistently better than performance in the outside-quadrant invalid condition. In particular, in Experiment 5 the probability of the target appearing in the within-quadrant invalid location was equal to the probability of the target appearing in either of the other two invalid locations, yet there was still a performance advantage for the within-quadrant location. Apparently, because the zoom-lens model does not include the spatial distance between attended and unattended locations as a functional parameter, the model cannot easily account for several aspects of the data which indicate that this distance is important.[2]

The gradient model. According to the gradient model (LaBerge & Brown, 1989), attending to a small compared with a large region of space is equivalent to creating a more narrow peak in a resource gradient. Performance for targets falling within such a peak is expected to be better than performance for targets falling within a more distributed peak if a smaller peak is also necessarily higher. How gradients change with changes in peak width is not made entirely clear in the LaBerge and Brown (1989) model, however. The simplest assumption seems to be that a more narrow peak is created by forming a higher, steeper gradient; that is, resources are removed from locations beyond the peak and added to locations at the peak when the peak is more narrowly focused (see Figure 8). With this assumption, a gradient model could account for all of the main results with regard to cued area size reported in this article. First, as indicated previously, a higher peak leads to greater facilitation following a small cue compared with a larger cue. Second, because resources fall off with distance from the peak, performance for the within-quadrant invalid targets is expected to be better than for invalid targets in other quadrants. Third, because a higher peak and steeper gradient forms following a small cue compared with a large cue, performance for targets at uncued locations is worse following small cues compared with large cues. Finally, because a neutral cue distributes resources evenly over the cued area, performance in the neutral condition is intermediate between that in the valid and invalid conditions (as shown in Figure 8).

The overall pattern of data reported in this article seems most easily accounted for by a gradient model of attentional allocation, according to which a more narrow, more steep, and more highly peaked resource gradient is formed when attention is allocated following a small cue in comparison to a large cue.

Conclusions

The present study presented evidence that concerns the allocation of covert visual–spatial attention following an ex-

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[2] C. W. Eriksen and St. James (1986) proposed that the focus of attention is surrounded by a small gradient fringe extending about 1.5° from the border of the cued area. Because the locations in the present study were a minimum of 5.24° apart (for the two locations within the same quadrant), however, it seems unlikely that targets at uncued locations would ever fall within this fringe area.
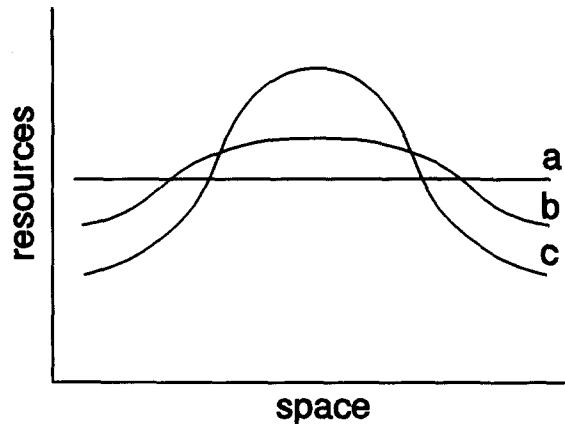
Figure 8. An illustration of a gradient model of attention. (Visual space is represented along the ordinate and performance [that reflects areas of relative facilitation and inhibition] is represented along the abscissa. The three curves represent the gradient when a neutral cue [a], large cue [b], or small cue [c] precede the target.)

ogenous cue. First, a clear and robust effect of exogenous attentional orienting was found on stimulus discrimination in an otherwise empty visual field. Second, when a small exogenous cue was used, maximal facilitation was found at the specific location cued. Performance for a stimulus appearing at another location within the cued quadrant was intermediate between performance for targets at the cued location and targets at more distant locations. Third, the size of the exogenous cue was found to modify the attentional effect: Cuing a smaller area led to greater facilitation at the cued location and greater inhibition at uncued locations. Although the zoom-lens model supplemented with a distance-sensitive reorienting mechanism could account for these results, a gradient view of attention seems to offer the most parsimonious explanation: A small exogenous cue produces a narrow, sharply peaked, steep gradient, whereas a large cue produces a broad, flat, less steep gradient. The steeper the gradient, the greater the facilitation at the center of the peak and the greater the inhibition in surrounding regions, in comparison to a neutral condition.

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