Covert and Overt Attention and the Processing of Cues for Location and Target Identification

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ABSTRACT. The authors compared covert and overt attention in a series of experiments designed to test some assumptions of space-based theories of visual attention. In Experiment 1, they measured reaction times (RTs) to a cued letter presented at varied eccentricities. When the letter's location was cued in advance by a bar marker, identification responses were found to be similar across a 20° area to the right and left of fixation. When related distractors were added to the display in Experiments 2 and 3, RTs were longer than in Experiment 1 and showed a U-shaped relationship with target and distractor distance. Only when the target letter appeared consistently in the center of the display was there evidence for a traditional spotlight with a unitary focus of attention. When both overt and covert attention conditions included multiple target locations, the data suggested that the distractor competed for attention and lengthened RTs in relationship to its distance from and compatibility with the target. The findings support an attentional mechanism that permits parallel access to noncontingent areas of the visual field.

IN THE PRESENT TASKS, we asked participants to selectively attend to a target letter at a cued location and to ignore a related distractor letter presented at varied distances. We investigated the role of retinal location on the processing of the target and distractor letters in order to examine some predictions of space-based theories of visual attention.

Traditional "spotlight" theories suggest that visual attention can be allocated either centrally or to any extrafoveal location and that any stimulus that falls within its beam will be processed. Support for space-based theories comes (a) from covert-attention studies that show costs and benefits in reaction times (RTs) to targets presented at cued, as compared with uncued, locations (Eriksen & St. James,
1986; Posner, Snyder, & Davidson, 1980) and (b) from studies showing the influence of a related distractor on target processing. Incompatible distractors located within a degree of visual angle of a foveal target interfered, whereas those at more distant locations did not (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1972). However, findings of distance effects at near, and not far, locations are not without controversy (Chastain, Cheal, & Lyon, 1996; Gatti & Egeth, 1978; Goolkasian, 1997; Goolkasian, 1999; Hagenaar & Van der Heijden, 1986; Miller, 1991).

The fact that both the flanker task and the location-cuing paradigm have been used to support traditional spotlight theories suggests that attention can be allocated to a cued location irrespective of where the location is on the retina and that little distinction is made between covert and overt attention. Covert attention is a term used in several recent studies (Carrasco & Frieder, 1997; Henderson & Maquistan, 1993) to represent the focusing of attention at an extrafoveal location without the use of eye or head movements. By comparison, we use the term overt attention to represent foveal processing.

Central, peripheral, or abrupt onset cues are generally used to direct attention to a target located at various eccentricities to the right or left of the fixation point. Studies have shown that cues differ in effectiveness as a function of where they are located. When compared with foveal cues, peripherally located cues are particularly effective at capturing attention (Jonides, 1981; Juola, Koshino, & Warner, 1995). However, there are differences of opinion as to why cues differ in effectiveness across retinal location. Some (Jonides; Juola et al.; McCormack, 1997) have suggested that different attentional systems are engaged—peripheral cues engage an exogenous system that is fast, automatic, and reflexive, whereas foveal cues require an endogenous system dominated by cognitive factors. The exogenous system is a response to external stimuli, whereas the endogenous system requires some voluntary control. Shepard and Müller (1989) found that exogenous cuing could be accomplished within 50 ms, whereas at least 200 ms were needed for endogenous cuing. Steinman, Steinman, and Lehmkuhle (1997) provided a neurophysiological explanation in the finding that cues that activated the magnocellular system captured visual attention more readily than did cues that activated the parvocellular system. Other studies (Theeuwes, 1991, 1994) have suggested that the difference in cue effectiveness depends on stimulus control and variables such as expected validity and timing.

In addition, although there is disagreement about both the shape and the size of the attended area, most space-based theories suggest a unitary focal point.

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Some researchers (Posner et al., 1980) have described the attended area as circular, covering 1° of visual angle, whereas others (Downing, 1988; Hughes & Zimba, 1985) have characterized it as broader, covering a wide retinal area (like a gradient), or as variable in size (like a zoom lens), depending upon the perceptual load (Eriksen & St. James, 1986; Lavie & Tsal, 1994).

Recently, attention researchers (Castiello & Umilta, 1992; Pylyshyn, 1994; Wright, 1994) have proposed a number of alternatives to the spotlight mechanism, each of which permits parallel access to more than one place in the visual field. Schmidt, Fisher, and Pylyshyn (1998) proposed a mechanism that operates in conjunction with the traditional “spotlight” to permit parallel processing of stimuli from multiple loci in the visual field. Driver and Baylis (1989) suggested an attentional mechanism that spotlights perceptual groups rather than a specific location on the retina. Moreover, Lavie (1995) has shown that physical separation between the target and distractor stimuli is not sufficient for selective attention. Some consideration of perceptual load must be made, and distractor interference is found only under low-load conditions.

In the present research, we investigated the effect of retinal location on the processing of a location cue and a related distractor, with the intent to sort out effects that may be attributable to visual factors (such as the reduced acuity with eccentricity) from attentional effects (presence or absence of the precue; distractor-compatibility effects). We used the findings to examine two assumptions from traditional space-based theories of visual attention—that covert and overt attention are similar and that visual attention has a unitary point of focus.

In some of the cuing studies, there is a relative confounding of type of cue with retinal location. Foveal (central) cues are often symbols—such as an arrow—that require some processing, whereas peripheral cues are bar markers adjacent to the target location. It is difficult to separate the effects of retinal location from endogenous-exogenous cuing. It may be that some of the differences in cue effectiveness relate to retinal location. Stimulus letters in all of the experiments reported here were presented at varied eccentricities, and their sizes were scaled to compensate for changes in resolution across the visual field to maintain visibility. The values used to scale the stimuli were in inverse proportion to the striate cortical magnification factor. This technique, referred to as M-scaling, was developed from the cortical magnification theory of peripheral vision, which proposes that stimuli presented at varied retinal locations can have equivalent visibility if their cortical representations are equivalent (Virtus, Nasanen, & Osmovita, 1987; Virtus & Revamo, 1979). Scaling the stimulus size can be an effective way of ensuring that stimuli are equally salient in foveal and extrafoveal locations (Carasaco & Frieder, 1997; Cheal & Lyon, 1989; Goolksian, 1999, p. 1008).

Also, some of the cuing studies (Juola et al., 1995; Theeuwes, 1991) use cue-target exposure durations that are long enough to permit eye movements toward the nonfoveal target locations. Even when eye movements are monitored during the trial, it is difficult to detect rapid movements toward an expected tar-
get location. To ensure peripheral target detection, exposure durations should be shorter than the time it takes to initiate an eye movement. Generally, an interval of 180–250 ms is needed to initiate an eye movement (Alpern, 1971; Saslow, 1967). In these experiments, stimulus letters are presented briefly (50 ms), and cue–target stimulus onset asynchrony (SOA) is manipulated to study the effect of precuing target location. Also, in Experiment 3, we used SOA intervals to manipulate covert and overt attention.

We investigated the effect that retinal location has on the processing of cues for location and target identification. Retinal location has been shown to influence perception in varied ways. First, there is a well-known decline in resolution with increasing eccentricity. However, Juttner and Rentschler (1996) have confirmed an observation made in 1857 by H. Aubert and R. Foerster that there is a qualitative difference between foveal and peripherally presented objects even when size adjustments are made to compensate for resolution differences. Patterns presented extrafoveally were found to have a reduced perceptual representation relative to foveally positioned patterns.

Second, it has been shown that attentional gradients may vary with eccentricity (Downing & Pinker, 1985; Sagi & Julesz, 1986; Steinman, Steinman, & Lehmkuhle, 1997). Sagi and Julesz suggested that the width of the attentional spotlight was related to retinal location when they showed that performance on a detection task varied as a function of a target’s proximity to a line target presented at several eccentricities. They reported that the size of the attentional area scales with eccentricity such that the size at 4° is twice that at 2° eccentricity. Similarly, Downing and Pinker concluded that attentional gradients at varied eccentricities were related to cortical magnification when they measured RTs to cued and uncued locations and found that the results were not homogeneous across the retina. If attentional gradients scale with eccentricity, then target processing may be influenced across broader distances depending upon foveal or peripheral presentation conditions.

Also, the findings from neurophysiological studies suggest that small eccentricities are particularly suited to target identification when letters or other text-based stimuli are used. When recording from cells in Area 17 of the brain, researchers (Grabowska & Nowicka, 1996; Tootell, Silver, & DeValois, 1981) found that sensitivity to high spatial frequencies was limited to an area smaller than 5° eccentricity, whereas sensitivity to low spatial frequencies was observed to be widely distributed (32° of visual angle).

Last, a number of studies have shown that retinal location is an important variable in determining distractor interference. Studies that require an observer to attend to competing foveal and peripheral stimuli typically show a decline in peripheral processing in association with an increase in the difficulty of the foveal task (Leibowitz & Appelle, 1969; Webster & Haslerud, 1964). Retinal location has also been shown to be important when low-load tasks are used and target and distractor stimuli are presented at varied retinal locations. Goolkasian (1981)
demonstrated that a foveally placed Stroop-like distractor interfered only with a near target. The interfering effect of the distractor was eliminated when the target appeared in the periphery. Recently, Carrasco, Evert, Chang, and Katz (1995) showed that the more centrally placed the target was in a visual search task, the more resilient it was to interference from distractors.

Our purpose in Experiment 1 was to measure RTs to scaled letters presented at varied eccentricities (0° to 20° of visual angle) when their locations had been reliably cued in advance by a bar marker. The location cue was presented with varied cue–target SOAs to assess the benefit of cuing across retinal location.

In Experiment 2, we then used the RTs across retinal location for target identification for comparison, to evaluate the added effect of a related distractor. The target letter was either a K or a D, and the distractor letter was compatible (same letter as the target), incompatible (the other target letter), or neutral (a nontarget letter such as M). We measured distractor-compatibility effects by comparing RTs for target letters accompanied by incompatible and compatible distractors. We compared neutral distractors with incompatible distractors to measure the interference effect and with compatible distractors to measure the facilitation effect.

In Experiment 2, the variable of primary interest was the region on the retina that was used for stimulus presentation. In the overt-attention condition, the target was foveal, whereas the distractor appeared in the periphery at varied distances from the target (1.6° to 20° of visual angle). In the covert-attention condition, the distractor was foveal, and the target appeared at varied distances. All other things being equal, are distance effects the same when a foveal target appears with a peripheral distractor and when a peripheral target appears with a foveal distractor?

In Experiment 3, we also compared overt and covert attention with target and distractor letters presented at wide distances, but both attention conditions used targets that appeared at varied distances from the foveal distractor. We manipulated covert–overt attention by varying the cue–target SOA interval in such a manner that, at the longest SOA, the participants had enough time to look directly at the target.

**EXPERIMENT 1**

In Experiment 1, target locations were reliably cued (100% valid) with a bar marker adjacent to the target location. Cues appeared in advance of the target with varied SOAs (0 ms, 40 ms, or 80 ms). Target locations varied on each trial from 0° to 20° to the right or left of a fixation area. Although it is well known that pre-cuing a target location facilitates target responding, our focus in this study was on measuring the benefit of the location cue across retinal location. Would the benefit be comparable at foveal as well as near and far peripheral locations? Other researchers (Jonides, 1981; Shepard & Müller, 1989) have shown that when compared with foveal cues, peripheral-location cues produced faster cuing and faster
target responses. However, this study differed from those previous efforts in a number of ways. We used the same location cue at each retinal location, whereas some of the other researchers used a symbolic cue in the foveal location, and the cue–target SOA was brief enough to preclude an eye movement in the direction of the target letter. Also, we scaled target-letter size to ensure equal visibility across retinal location. Scaled stimuli have been used previously in cued-attention tasks to ensure equal target discriminability across eccentricity (Carrasco & Yeshurun, 1998; Cheal & Lyon, 1989). We measured the benefit from precuing a location by comparing RTs with simultaneous presentation of the cue and target with those SOA conditions in which participants were provided with some advance warning of where the target would appear.

The target was a letter—K or D—that appeared for 50 ms and was masked after the offset of the stimulus to control the amount of time that the stimulus was visible. The location cue was a bar marker (see Figure 1). The target-exposure duration and the cue–target SOA were long enough to process the target clearly but shorter than the 180–250 ms needed to initiate an eye movement (Alpern, 1971; Saslow, 1967).

![Figure 1. Timing of the stimulus displays.](image)
Method

Participants

Participants in Experiments 1 and 2 were 31 male and female students from the University of North Carolina, Charlotte. They all reported normal (or corrected-to-normal) vision and no history of eye impairment; they participated to obtain credit points in a psychology class. The students participated in Experiments 1 and 2 successively, and both experiments were undertaken with the understanding and written consent of each participant.

Stimulus Materials

The target letters were upper-case letters, produced from the Macintosh character set (Geneva font). Scaling the letter size involved varying points where each point equaled .014°. The letters were printed in black against a bright background with a luminance of 121 cd/m². The letters were black with a luminance of 24.30 cd/m². (Luminance was measured with a Minolta luminance meter LS 100.)

The target letter, either a K or a D, varied in size as a function of location. The target appeared at a central location (0°) or at one of the following peripheral locations either on the right or left side of the fixation area: .62°, 1.25°, 2.5°, 5°, 10°, or 20° of visual angle. Letter sizes were scaled such that the letter's width was always half the letter's height. Scale values were derived from the following formula (Virsu & Rovamo, 1979): \( M = 7.99 \left( 1 + .33E + .00007E^3 \right) \), in which \( M \) is the cortical magnification factor and \( E \) is eccentricity in degrees of visual angle. The values of \( M \) calculated for each of the six distances in order of increasing eccentricities were 6.63, 5.65, 4.37, 3.00, 1.83, and .97. When letter sizes were scaled in proportion to a foveal value of 7.99, they were 1.21 times the size at the nearest location and 8.17 times the target size at the farthest location. We used the following letter sizes for the scaled stimuli in order of increasing eccentricity: 7, 8, 10, 13, 19, 31, and 57 points. With the participant seated 30 cm from the screen, the visual angles subtended by the letter heights were .47°, .57°, .67°, .86°, 1.26°, 2.07°, and 3.88°, respectively.

We used a bar marker to cue the target location. The bar marker was a black line (.38° × .95°) positioned 6–7 cm below the center of the target location. The stimuli were displayed on an NEC color high-resolution 19° monitor. The monitor used a P22 phosphor with a medium-short persistence. Stimulus presentation and data collection were controlled by SuperLab running on a Quadra 840 AV. The task was fully automated. SuperLab programming features such as instant switching and refresh line synchronization were used to precisely coordinate the presentation of the stimuli and the recording of the RTs.
Procedure

The events on each trial are displayed in Figure 1. Trial onset was automatic and began with fixation arrows that appeared for 500 ms. The participants were instructed to keep their eyes on the center of the visual field (the area between the arrows). A bar marker cued the target location, and it appeared either simultaneously (0 ms) or in advance (40 ms or 80 ms) of the target. After a 50-ms target duration, a mask terminated the stimulus and remained on the screen until the participant made a key-press response. The mask was a grating of diagonal lines (.5 mm wide) with a luminance of 60.77 cd/m² that covered a 15° × 48° area. RTs measured the time between presentation of the target letter and the key-press response.

The students participated in individual sessions of approximately 35 min. A chin rest was used to stabilize head movements and to maintain fixation on the center of the screen. The participants were instructed to keep their eyes on the center of the screen and to identify the target letter as quickly as they could by pressing K or D on the keyboard. Each student participated in a block of 30 practice trials and then in a block of 252 trials. There was a random arrangement of the seven presentation locations (0°, 62°, 125°, 250°, 5°, 10°, and 20° of visual angle) and three SOAs (0 ms, 40 ms, and 80 ms). There were 12 replications of each of the 21 experimental conditions. For the peripheral presentation locations within each of the 12 replications, there was an equal number of targets positioned in the right and left visual fields.

Results

We computed the means presented in Figure 2 from the correct RTs and the proportions of incorrect responses obtained from each participant across the 12 trials within each experimental condition. We used a 3 × 7 repeated-measures analysis of variance (ANOVA) on the RTs and the error data to test for the effects of cue–target SOA and retinal location. We did not include in the analysis responses to any one trial that were longer than 1200 ms. (We excluded less than 1% of the responses for this reason.) We did not include in the analysis the data from 1 participant because of excessive errors. To test for the sphericity assumption, we used the F tests reported in Experiments 1, 2, and 3 to calculate epsilon factors for each of the main and interaction effects. We used the Geisser–Greenhouse correction in any instance in which a violation was indicated.

Reaction Time

RTs were significantly shorter when the cue appeared in advance of the target, F(2, 58) = 23.67, p = .0001. On average, there was a 16-ms advantage with a cue presented 40 ms in advance of the target, and there was a 26-ms advantage
FIGURE 2. Mean correct reaction times (in milliseconds) and error rates for the interaction effect of cue–target stimulus onset asynchrony and target location in Experiment 1. The horizontal axis is logarithmic.

with a cue presented 80 ms in advance. RTs also varied with presentation location, $F(6, 174) = 5.58, p = .0001$, and with the interaction of SOA and presentation location, $F(12, 348) = 2.04, p = .02$. A test for simple effects of retinal location at each of the SOA conditions showed that the interaction resulted from a main effect of retinal location under the simultaneous-SOA ($p = .006$) and 40-ms-SOA ($p = .009$) conditions but not with the 80-ms-SOA condition ($p = .32$). We also conducted post hoc tests ($p < .05$ level of significance) at each location to assess the benefit from precuing location when compared with the 0-ms-SOA condition. The findings showed significantly shorter RTs at each of the retinal locations tested (except 2.5°) when preview was 80 ms and at 3 of the 6 peripheral locations when a 40-ms preview was provided.
Errors

Error rates were not found to vary by SOA condition, $F(2, 58) = 1.57$, $p = .21$; by retinal location, $F(6, 174) = 1.53$, $p = .17$; or by their interaction, $F < 1$. Error rates for simultaneous, 40-ms, and 80-ms SOAs were .04, .04, and .05, respectively.

Discussion

Precuing location, as compared with simultaneously cuing location, resulted in shorter RTs for targets presented at all of the presentation locations with the exception of 2.5° of visual angle. A 40-ms preview provided a benefit for some of the peripheral locations, but facilitation of foveal target detection occurred only when the cue appeared 80 ms in advance of the target.

Differences in RTs to targets located across a 40° field of view (20° to each side of a fixation area) narrowed with increasing cue–target SOA. When letter sizes were scaled in size and the participants were provided with sufficient time (80 ms) to covertly orient attention, target RTs were equivalent, irrespective of where the target was located. This finding is consistent with other cuing studies that used scaled stimuli (Carrasco & Yeshurun, 1998; Cheal & Lyon, 1989). A cue appearing 40 ms in advance had somewhat the same effect with the exception of the foveal location. When the location cue appeared simultaneously with the target, the participants took longer to respond to the target presented at the farthest eccentricity as compared with their RTs for targets at nearer eccentricities. Thus, the major effect of the 80-ms preview of the location cue was to remove the variation in RTs across retinal location.

The latency difference across retinal location was evident in the 0-ms-SOA condition when the location cue appeared simultaneously with the target. Target detection was lengthened in relationship to target eccentricity. However, the latency difference did not reflect sensory differences in the way letter stimuli were processed across retinal location. Such an explanation would have caused a consistent retinal location effect across all of the SOA conditions. Instead, these findings are in agreement with the cuing literature in demonstrating that providing a location cue adjacent to the target is an effective way of covertly orienting a participant’s attention to the target location. A benefit from exogenous cuing was evident at all locations except 2.5° eccentricity, and it is not clear why it was absent at this location. Interestingly, the finding that the 40-ms-SOA condition resulted in significantly shorter RTs at three of the six peripheral locations, but not at the foveal location, suggests that peripheral cuing may be accomplished more quickly than foveal cuing. Shepard and Müller (1989) reported a similar finding even though they used a symbolic cue at the foveal location. The finding is also consistent with the explanation of Steinman et al. (1997)—cues that activate the magnocellular system capture visual attention more rapidly than cues that activate the parvocellular system.
The data in Figure 2 present the basic RTs across eccentricity for cued-target identification and provide a basis for comparison with the results of the following experiments to determine the relative degree of interference and facilitation attributable to the processing of related distractors.

EXPERIMENT 2

As in Experiment 1, target location was reliably cued with a bar marker that appeared in advance of the stimulus letters. However, in Experiment 2, we added to the stimulus display a distractor letter that varied in compatibility with the target. Because the distractor letter was related to the target, it functioned to prime the target response. The question of interest was whether distractor processing would vary when overt and covert attentional processes were compared.

Targets and distractors appeared briefly (50 ms) at varying distances (.6° to 20° of visual angle) in one of two presentation conditions (foveal target–peripheral distractor or peripheral target–foveal distractor). In a previous study with scaled stimuli, Goolkasian (in press) showed compatibility effects (differences between compatible- and incompatible-distractor conditions) at far distances (out to 5° of visual angle from the target) and some variation in the shape of the RT function with presentation conditions. In the peripheral–foveal condition, RTs across target–distractor distance were U-shaped rather than linear: To provide a more comprehensive assessment of distractor effects in the present research, we extended that effort by comparing RTs to target and distractor stimuli with RTs to a target presented alone (Experiment 1). Relative benefits and costs across distance and location can be compared with absolute changes that resulted from the addition of another letter to the display. The addition of a foveal distractor to a cued-attention task might have effects on target processing different from the addition of a peripheral distractor. In past studies, when foveal and peripheral stimuli competed, there was typically a decline in peripheral performance (Leibowitz & Appelle, 1969; Webster & Haslerud, 1964).

To what degree would distractor processing occur even though the participants were precued to the target location? According to space-based theories of attention, distractor processing should occur only when it falls within the attentional focus. Traditional spotlight theories would limit distractor effects to locations near the target with both presentation conditions. Predictions would be the same whether attention was centrally (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1972) or covertly (Posner et al., 1980) oriented. Zoom-lens models would allow the attentional area to expand with the target–distractor distance, but there would be some commensurate loss in resolving power, and the focal area would be unitary (Eriksen & St. James, 1986; Pan & Eriksen, 1993). Similarly, the gradient models would predict that attention would be broadly distributed across a wide retinal area but that there would be some gradual change in processing efficiency across the area (Downing & Pinker, 1985; Hughes & Zimba, 1985). Find-
ings consistent with space-based theories should show distractor effects that vary in a simple way with distance from the target, and there should not be any difference in the spatial distribution of attention between the two presentation conditions. Findings of distractor effects that do not decline with distance from the target or that vary with presentation location might suggest more than one focus of attention.

In Experiment 2, the location cue appeared 50 ms in advance of the stimulus display and reliably cued the target location. On the basis of the results of Experiment 1, an SOA of 50 ms would be sufficient for exogenous cuing at peripheral locations and would minimize the possibility of an eye movement in the direction of the target letter. We blocked the two presentation conditions to avoid any misunderstanding among the participants regarding the target location. In the overt-attention condition, the target was presented consistently at the fovea, and the distractor location varied on each trial; in the covert-attention condition, the target location was varied on each trial, and the distractor was consistently presented in the fovea. However, the fact that target location was fixed in one condition and varied in the other provides an alternate explanation for any differences between presentation conditions. We conducted Experiment 3 to remove this confound by testing only the peripheral-target–foveal-distractor condition under short and long cue–target-SOA conditions so that participants could use eye movements to view the targets presented at far eccentricities.

Method

The stimulus materials were the same as those in Experiment 1, with the addition of the distractor letter. The distractor letter—K, D, or M—appeared simultaneously with the target. The center-to-center distance between the target and distractor was varied so that distance effects could be measured at each of these eccentricities: .62°, 1.25°, 2.5°, 5°, 10°, and 20° of visual angle. Also varied in two blocks of trials were the presentation locations of the target and distractor letters. In one block, the distractor was centrally located, whereas the target appeared at varying distances to the right or left. In the other, the target was centrally located, whereas the distractor appeared at varying distances to the right or left. The peripheral letter was always scaled relative to the foveal letter. The scale values were the same as those reported in Experiment 1.

The procedure on each trial is outlined in Figure 1. The bar marker followed the fixation arrows for 50 ms to cue the target location. The target letter and the distractor letter were superimposed on the display for an additional 50 ms. A mask terminated the stimulus events and remained on the screen until a key press was made. The participants were instructed to keep their eyes between the fixation arrows and to identify the target letter as quickly as they could without making any errors. Each participant first received 30 trials as practice and then 432 experimental trials. These trials represented 12 replications of the 36 experimental con-
ditions; within each of the 12 replications, there was an equal number of letters presented to the right or left of the fixation point. Trials were divided into two blocks presented in counterbalanced order. The two blocks represented the two presentation conditions—foveal target–peripheral distractor and foveal distractor–peripheral target. Within each block, there was a random arrangement of three distractor-compatibility conditions and six distractor distances. In all other respects, this experiment was similar to Experiment 1.

Results

We used a $2 \times 6 \times 3$ repeated-measures ANOVA on the RT and the error data to test for the effects of retinal region (foveal target–peripheral distractor vs. peripheral target–foveal distractor), target–distractor distance, and distractor compatibility. We did not include in the analysis data from 1 participant because of excessive errors. We did not include in the analysis RTs in excess of 1200 ms (less than 2% of the responses).

Reaction Time

The analysis showed significant main effects of retinal region, $F(1, 29) = 61.88, p = .0001$; distractor compatibility, $F(2, 58) = 38.48, p = .0001$; and target–distractor distance, $F(5, 145) = 50.27, p = .0007$. As expected, RTs were shorter (a) when targets appeared in the fovea with peripheral distractors than when the targets appeared in the periphery with foveal distractors; (b) when a compatible, as compared with an incompatible, distractor appeared; and (c) when there was greater distance between the target and distractor letters. Moreover, retinal region was found to interact with distractor distance, $F(5, 145) = 7.18, p = .0001$, and with distractor compatibility, $F(2, 58) = 8.78, p = .0005$; and distractor compatibility interacted with distractor distance, $F(10, 290) = 6.78, p = .0001$. However, the three-way interaction was not significant, $F < 1$.

Figure 3 contains the mean correct RTs for all of the experimental conditions under study. Figure 3a represents responses when the target appeared in a foveal location and the distractor appeared at varied distances in the periphery. Compatibility effects (RT differences between compatible and incompatible distractors) were obtained primarily when peripheral distractors were located at a distance of 2.5° or less of visual angle. Table 1 contains the results of post hoc tests that analyzed these effects into facilitation and interference effects.

RTs to foveally placed targets declined with increasing distance of the peripheral distractors, and interference from incompatible distractors decreased with distance from the foveal target. When positioned at eccentricities beyond 2.5° of visual angle, there was little evidence that participants processed the distractors. A comparison of these findings with the findings from the first experiment shows similar RTs when participants detected the foveal target at a cued
FIGURE 3. Mean correct reaction times (in milliseconds) and error rates for the interaction of distractor compatibility and target-distractor distance in Experiment 2. The horizontal axis is logarithmic. The data collected in Experiment 1 (80-ns stimuli) and Experiment 2 (20-ns stimuli) are represented by x's and are presented for comparison.
TABLE 1
The Distractor-Compatibility Effect Divided Into Interference (Incompatible–Neutral Distractor) and Facilitation (Neutral–Compatible Distractor) Effects

<table>
<thead>
<tr>
<th>Distance</th>
<th>Compatibility</th>
<th>Interference</th>
<th>Facilitation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Foveal target-peripheral distractor</strong></td>
<td></td>
<td></td>
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<tr>
<td>0.62°</td>
<td>56*</td>
<td>33*</td>
<td>23*</td>
</tr>
<tr>
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<td>21</td>
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<tr>
<td>2.50°</td>
<td>61*</td>
<td>34*</td>
<td>27*</td>
</tr>
<tr>
<td>5.00°</td>
<td>31*</td>
<td>19</td>
<td>12</td>
</tr>
<tr>
<td>10°</td>
<td>16</td>
<td>19</td>
<td>-3</td>
</tr>
<tr>
<td>20°</td>
<td>47*</td>
<td>16</td>
<td>31*</td>
</tr>
</tbody>
</table>

*p < .05.

location without the distractor. The average RT in Experiment 1 to a foveal target when location was precued (80-ms SOA) was 418 ms.

Figure 3c represents the responses to peripheral targets with foveally located distractors. At this presentation condition, the RT function across target–distractor distance was U-shaped. A trend analysis showed significant linear (p = .0001) and quadratic components (p = .0001). Responses became quicker as the target–distractor distance became wider until the function bottomed out at 5° of visual angle. When these responses are compared with the data in Experiment 1, it is quite clear that even though the peripheral target appeared at the same eccentricities, the addition of the foveal distractor lengthened RTs.

In Table 1, we compared the compatibility effect for the two retinal regions across comparable target–distractor distances. In comparison with the other presentation condition, foveal distractors produced larger and more extensive interference and facilitation effects. However, consistent with the findings at the other presentation location, the effect of the incompatible distractor decreased with distance and appeared to have been minimized at 5° of visual angle. Interestingly, RTs began to increase with far eccentricities. At the farthest eccentricity, there was a significant facilitation effect attributable to the compatible distractor. At this location, however, even when the foveal letter was the same as the target letter, RTs were longer than they were in Experiment 1 when the peripheral target appeared alone.
Errors

Error rate was found to vary as a function of distractor compatibility, $F(2, 58) = 6.78$, $p = .0001$, and target–distractor distance, $F(5, 145) = 5.16$, $p = .0002$. There was no main effect of retinal region, $F < 1$; but retinal region interacted with distractor compatibility, $F(2, 58) = 5.39$, $p = .007$, and distractor distance, $F(5, 145) = 2.59$, $p = .03$. From Figure 3, it appears that these effects resulted from (a) more errors when incompatible distractors appeared at the fovea as compared with incompatible distractors presented at nonfoveal locations and (b) more errors when participants identified targets at $20^\circ$ of visual angle with foveal distractors. None of the other effects in the analysis were significant.

Discussion

The findings show that in a cued-attention task, the processing of compatible distractors depends upon their retinal region as well as their distance from the target. Peripherally placed distractors interfered with the detection of foveal targets only when they appeared within $2.5^\circ$ of visual angle. The finding that target RTs were no different from RTs collected in Experiment 1 (when the target appeared foveally without the distractor) suggests that peripheral distractors, in spite of their scaled sizes, were not processed when they appeared at the three farthest eccentricities. For this presentation condition, the results are consistent with space-based theories of attention and suggest that when participants were responding to a cued-attention task, only an area within $2.5^\circ$ of visual angle around the target was sensitized and available for processing. Otherwise, the presence of peripheral distractors was not influencing target detection. The error data also support this interpretation. Elevation in errors occurred only when incompatible and neutral distractors appeared near the target ($6^\circ$ of visual angle).

Distractor effects were stronger, however, when they were positioned at the fovea and the participants covertly oriented toward a peripheral target. RTs at each of the target locations were longer than RTs from Experiment 1 when the targets appeared at the same cued locations without the foveal distractor. The finding that the very presence of the distractor lengthened RTs at each of the locations tested suggests that the foveal distractor competed with the peripheral target for attention. At the same time that participants were covertly orienting their attention to the peripheral target, they also appeared to be devoting some processing resources toward the distractor letter. Even when the distractor was the same letter as the target (compatible distractor), RTs were at least 50 ms longer than they were in Experiment 1, presumably because of the presence of the foveal letter. Neutral and incompatible distractors delayed target processing even more at the 3 nearest eccentricities.
In addition, most interesting was the U-shaped nature of the relationship between RTs and target location. The 5° location appeared to mark a transition between two attentional mechanisms. When targets were presented at the near eccentricities (less than 5° of visual angle), their processing was affected by the foveal distractor in a way similar to that observed with peripheral distractors and foveal targets—that is, when the participants were attending covertly to a target at a given location, a broad area (2.5° of visual angle) was sensitized and available for processing. The finding that interference effects and error rates declined with target–distractor distance supports this interpretation. When targets appeared at farther eccentricities (beyond 5° of visual angle), however, the foveal distractor fell outside the focus of attention and appeared to compete with the target for the participant’s attention. The increase in RTs to targets positioned at the two farthest eccentricities could be a result of the participants’ dividing their attention between the peripheral target and the foveal distractor. The finding that the foveal distractor produced a significant facilitation effect at the farthest eccentricity and a significant increase in the error rate in response to incompatible distractors suggests that participants are processing the distractor letter.

It is also possible that these data reflect a stretching of attention across the target and distractor letters rather than a division of the attentional focus. Both the zoom-lens model and the gradient model allow attention to be broadly distributed, but generally the breadth comes at some loss of processing capacity. The results at target–distractor distances of 5° or less of visual angle are consistent with both of these models because compatibility effects declined commensurately with increases in target–distractor distance. Much harder to explain, however, are the results at target–distractor distances beyond 5° of visual angle. The long latencies and increased errors at the farthest eccentricity, in comparison with data collected at 5° and 10° eccentricities, are difficult to explain within a zoom-lens or gradient framework.

Longer target responses in the peripheral–foveal condition than in the other presentation condition may also have resulted from a difference in the number of possible sites for the target. Even though target location was reliably cued in all conditions, in the foveal target condition, the target appeared consistently in the center of the display, whereas the peripheral condition used multiple sites. Constancy of location has been shown to enhance selective attention (Miller, 1991). The data from the foveal-target condition suggested ideal conditions for selective attention. Attention was centrally focused, and distractor letters were processed only when they fell within the spotlight. The finding that RTs with far distractors (beyond 2.5°) were comparable to latencies collected in Experiment 1 without the distractor letter confirms that participants ignored the distractors that appeared outside the focus of attention. We conducted Experiment 3 to sort out the effects that were attributable to covert–overt attention from those attributable to single-versus multiple-target locations.
EXPERIMENT 3

We used long and short cue–target SOA intervals to compare overt and covert attention. The procedure was the same as the peripheral target–foveal distractor condition in Experiment 2. Target location varied on each trial (.62° to 20° of visual angle from the fixation area) but was reliably cued with a bar marker. The distractor letter appeared consistently in the fovea, and target and distractor letters were simultaneously presented for 50 ms.

We presented three SOA intervals (0 ms, 50 ms, and 300 ms) in separate blocks of trials. Performance under covert attention was associated with the short SOA intervals—0 ms and 50 ms. For these trials, the combination of cue–target SOA and stimulus-exposure duration was less than the time needed to make an eye movement in the direction of the target. In order to maximize performance, participants needed to keep their eyes in the center of the visual field and covertly attend to the peripheral targets. However, in the long (300-ms) SOA condition, the bar marker appeared in advance with enough time to permit an eye movement toward the target location. Performance in this condition was most likely associated with overt attention. We were interested in learning if the same covert–overt attention differences (identified in Experiment 2) in the shape of the RT function with target–distractor distance would reoccur when target presentation conditions were comparable.

In this experiment, target position varied on each trial, necessitating a broad attentional focus in advance of the exogenous cue identifying the target location. If the U-shaped function identified in Experiment 2 resulted from switching attention between the centrally located distractor and the peripheral target, one would expect that effect to vary with cue–target SOA interval. Fox (1995) and Paquet and Lortie (1990) showed that precuing target location increased attentional selection and decreased the interfering effect of the distractor. Effects consistent with the switching-attention hypothesis would show that distractor compatibility effects would be maximized at the 0-ms-SOA condition and minimized at the longest SOA interval. Because attention was centrally focused at the start of the trial in the 0-ms-SOA condition, it was possible for participants to process the distractor before covertly orienting toward the cued location. In the other SOA conditions, however, there was sufficient time to orient attention away from the fovea before target onset because the location cue appeared in advance of the target. Under these circumstances, it was less likely that participants would switch attention between the foveal distractor and the peripheral target.

Method

The 29 participants were drawn from the same population as the participants in the previous experiments. The procedure and stimulus materials were
the same as those in the peripheral target–foveal distractor condition in Experiment 2. Scaled target letters appeared in one of six peripheral locations to the right or left of a foveal distractor letter. The distractor varied in compatibility (compatible, neutral, incompatible) and in distance (.62° to 20° of visual angle) from the target.

We varied cue–target SOA in blocks of trials. Each block comprised 216 trials that were randomly mixed combinations of the 18 Location × Compatibility conditions. The 3 SOA conditions (0 ms, 50 ms, and 300 ms) were presented in one of three Latin square orders to partially balance the presentation of the SOA conditions. The participants received 30 practice trials and 648 experimental trials. In all other respects, Experiment 3 was similar to Experiment 2.

Results

We used 3 × 3 × 6 repeated-measures ANOVAs on the RT and the error data to test for the effects of cue–target SOA condition, distractor compatibility, and target–distractor distance. We did not include in the analysis data from 3 participants because of excessive errors. We did not include RTs in excess of 1200 ms (less than 1% of the response).

Reaction Time

Cue–target SOA conditions influenced the error data but did not have any significant effect on the RT analysis. There was no SOA main effect, F < 1; no interaction with distractor compatibility, F < 1; no interaction with target–distractor distance, F < 1; and no three-way interaction, F < 1.

Distractor-compatibility effects, however, were found to vary by target–distractor distance, F(10, 250) = 4.15, p < .0004; and there were significant main effects of compatibility, F(2, 50) = 36.62, p < .0001, and distance, F(5, 125) = 4.15, p < .0004. As in the peripheral-target condition from Experiment 2, a trend analysis on the distance effect showed significant linear (p = .0001) and quadratic (p = .0001) components. Post hoc comparisons (p < .05) showed significant compatibility effects for distractors that were positioned at 2.5° or less of visual angle from the target and for distractors positioned at the greatest distance (20°). Interference from the incompatible distractor was the larger contributor to the compatibility effect at the three near locations, whereas facilitation from the compatible distractor was obtained at the closest and farthest locations. Figure 4 contains the interaction broken down by SOA condition.

Errors

Variation in the cue–target interval had a significant influence on errors. There was a main effect of SOA, F(2, 50) = 3.86, p = .04, and a significant inter-
FIGURE 4. Mean correct reaction times (RTs) and error rates for the interaction of distractor compatibility and target–distractor distance in Experiment 3. The horizontal axis is logarithmic. SOA = stimulus onset asynchrony.
action of SOA and distractor compatibility, \( F(4, 100) = 3.12, p = .03 \). As can be seen in Figure 4, these effects indicated a decline in number of errors and size of the compatibility effect with increasing SOA interval. Performance was more accurate at 300-ms SOA than at the shorter SOAs.

The distractor-compatibility effect, \( F(2, 50) = 17.49, p = .0001 \), indicated that most errors were made in response to incompatible distractors and the fewest to compatible distractors. The number of errors with target–distractor distance showed the same U-shaped trend identified in the RT analysis, \( F(5, 125) = 5.82, p = .0008 \). However, the Compatibility \times Distance interaction was not significant, \( F(10, 250) = 1.12, p = .35 \).

**Discussion**

Lengthening the time to process the cue for location had the expected effect of enhancing the participants’ selective attention to the target, but the effects were evident on the error rate and not on the RT data. In the long SOA condition when there was sufficient time to look directly at the target location, accuracy was highest, and there was less evidence of distractor processing (smallest compatibility effect).

Most important, SOA condition did not cause a change in the shape of the relationship between RT and target–distractor distance. It is unlikely, then, that the results can be explained by the participants’ switching attention between the target and distractor letters. Such a mechanism would have been much more likely when there was no precue for location and would have caused some SOA effect on the RTs. The distinctive U-shaped relationship associated exclusively with covert attention in Experiment 2 was found at all SOA conditions. Figure 4 shows this trend in the data for all six panels. When target location varied from trial to trial, whether a target was viewed overtly or covertly, distractor processing depended on its distance from the target. When located close together (within 2.5° of visual angle), incompatible distractors interfered, and—to a somewhat lesser extent—compatible distractors facilitated target processing. The effect of related distractors diminished with distance. When presented at somewhat greater distances (beyond 5° of visual angle), however, the presence of the distractor began to compete with the target as though there were two attentional foci. Only when compatible distractors appeared did the competition diminish. There is evidence for distractor processing both inside and outside the spotlight of attention. The key ingredient is not the presentation location as suggested by the results of Experiment 2 but rather the expected target location. When participants expected the target to appear across a broad field of view, the presence of a related distractor interfered with target detection, whether or not that target was viewed directly or through covert attention. As in Experiment 2, the results for target–distractor distances beyond 5° of visual angle did not fit predictions of zoom-lens or gradient models.
GENERAL DISCUSSION

When taken together, the findings from these three experiments shed some light on two assumptions of space-based theories of attention. The first experiment dealt with a comparison of overt and covert attention. Although there were some retinal-location differences, processing a location cue and a related distractor letter were comparable under covert and overt attention.

In Experiment 1, we showed that responses to targets presented across wide eccentricities can be just as efficient as responses to foveal targets as long as attention can be oriented to the target location in advance. A bar marker positioned adjacent to the target site was an effective cue that appeared to exogenously orient attention across retinal location. The finding that slightly longer preview was needed for the foveal location than for a number of other peripheral locations may reflect underlying sensory differences. Steinman et al. (1997) showed that cues that activated the magnocellular system captured visual attention more rapidly than did cues activating the parvocellular system. However, with sufficient preview of the location cue and the use of scaled targets, target-identification responses were similar across a $20^\circ$ area to the right and left of fixation. When some effort is made to control differences in visual factors across retinal location, then target latencies are comparable, as found by Cheal and Lyon (1989).

When we added related distractors to the display in Experiments 2 and 3, effects of retinal location in the processing of these cues were evident with both the RT and the error data. However, in Experiment 3, we showed that the RT differences associated with presentation location in Experiment 2 were attributable primarily to differences in possible target locations. When both overt- and covert-attention conditions included multiple target locations, then the RT data showed a similar U-shaped relationship with target–distractor distance. The major difference between the overt- and covert-attention conditions was in the overall error rate. The overt-attention condition (300 ms SOA) was associated with fewer target-identification errors than was the covert-attention condition.

Our findings in these experiments are less consistent with the second assumption of a unitary focus of attention. Across all the experiments, perceptual load was low, and the target location was reliably cued (100%); yet, the processing of the distractor letter was not related simply to its distance from the target as suggested by space-based theories of attention. We obtained evidence for a unitary focus of attention only in Experiment 2 in the foveal-target condition (Figure 2a) when the participants knew that the target would occur consistently in the center of the display. The finding that foveal target latencies were lengthened only when the peripheral distractors were located at $2.5^\circ$ or less is consistent with a number of other studies that show distance effects beyond a $1^\circ$ area (Gatti & Egeth, 1978; Goolkasian, 1997; Hagenaar & Van der Heijden, 1986; Miller, 1991) and provide evidence for a space-based theory of attention with a broad spotlight (Downing, 1988; Steinman, Steinman, & Lehmkuhle, 1995).
When target location varied, however, there was evidence that the participants processed the distractor even when it appeared at far distances (20° of visual angle). The finding that the RTs for Experiment 3 were longer than those in Experiment 1 and curvilinear with distance shows that the distractor stimulus was processed. The distractor influenced target detection even though it appeared at a distance much beyond a traditional narrow spotlight. The data suggest that the participants' attention was divided between the two stimulus letters. The distractor letter competed with target processing and lengthened RTs in relationship to its distance and compatibility. Interpretation of the findings within a zoom-lens model (Eriksen & St. James, 1986; Pan & Eriksen, 1993) or a gradient model (Downing, 1988; Hughes & Zimba, 1985) would explain why RTs in Experiment 3 were longer than in Experiment 1. Stretching attention across the target–distractor distance would explain why foveal distractors were influencing target processing even at distant locations, but these models cannot explain the U-shaped relationship between RT and target–distractor distance. Predictions from these theories were that distractor interference would gradually diminish or that target RTs would lengthen with increasing target–distractor separation. The complex U-shaped relationship is difficult to explain within these theories.

It does not appear from our findings that the results can be explained at a purely physiological level. Although sensitivity to high spatial frequencies was limited to an area smaller than 5° eccentricity, the data from Experiment 1 showed that with sufficient warning regarding where a target would appear, participants were just as able to identify scaled target letters at 20° eccentricity as to identify foveally located targets. The curvilinear RT function with target–distractor distance resulted from the processing of the distractor letter and occurred when either covert or overt attention was directed at the target location.

The findings of these experiments are consistent with a number of other findings (Carrasco & Yeshurun, 1998; Castiello & Umiltà, 1992; Driver & Baylis, 1989; Pylyshyn, 1994; Wright, 1994) that point to an attentional mechanism that permits parallel access to noncontingent areas of the visual field. It may, as suggested by Schmidt et al. (1998), operate in conjunction with the traditional spotlight notion because the RT data show distractor interference effects within 2.5° decline with distance. But there is no doubt that by itself the spotlight mechanism with its unitary focus of attention is not sufficient to explain these data. Further experiments are needed, however, to examine the characteristics of the attentional mechanism beyond the spotlight.

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