Retinal location and its effect on the spatial distribution of visual attention.

by Paula Goolkasian

A series of studies tested for distractor compatibility effects across wide target/distractor distances (0.6 [degrees] to 20 [degrees] of visual angle). The effects of precue condition, constant/varied target location, horizontal/vertical distractor distance, and foveal/peripheral presentation were studied. Results show strong compatibility effects across wide distances when distractors are at peripheral retinal locations. When both stimuli were presented at the same peripheral location in opposite hemifields, compatibility effects were evident within an area of at least 2.5 [degrees] of visual angle. In contrast, when foveally placed distractors were used, compatibility effects were found primarily with target letters positioned near. The findings suggest that distance effects are not homogeneous across retinal location.

Space-based theories of visual attention suggest that attention can be covertly allocated to an extrafoveal location, but there is some disagreement as to the width of the attended area. Some suggest an area that is circular (like a spotlight) covering 1 [degree] of visual angle (Posner, Snyder, & Davidson, 1980); others describe it as broader, covering a wide retinal area (like a gradient) (Downing, 1988; Hughes & Zimba, 1985) or as variable in size (like a zoom lens), depending on the perceptual load (Eriksen & St. James, 1986; Lavie & Tsal, 1994). Support for space-based theories comes from distance effects as measured in attention studies that show costs and benefits in reaction times (RTs) to targets presented at cued as compared to uncued locations and from studies showing the influence of a related distractor on target processing. Incompatible distractors located within a degree of visual angle of a target interfered and 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 controversial (Chastain, Cheal, & Lyon, 1996; Gatti & Egeth, 1978; Goolkasian, 1997; Hagenaar & Van der Heijden, 1986; Miller, 1991).

This investigation studied the role of retinal location on the spatial distribution of visual attention. Although it is well known that attention can be covertly oriented to a target located at varying eccentricities from the point of fixation, it is not known how retinal location influences the distribution of attention. 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? What happens when both target and distractor appear at extrafoveal locations?

At least three lines of evidence suggest some difference in the extensiveness of distance effects at varied retinal locations. First of all, Juttner and Rentschler (1996) recently confirmed an observation made in 1857 by Aubert and 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 lower perceptual representation than 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 (1986) 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 test flash’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 [degrees] is twice that at 2 [degrees] eccentricity. Similarly, Downing and Pinker (1985) concluded that attentional gradients at varied eccentricities were related to cortical magnification when they measured costs and benefits to cued and uncued locations and found that the results were not homogeneous across the retina. Costs were greater for stimuli closer to the fovea. Their data also show an effect related to endpoints, such that benefits are greater and gradients steeper when cued locations are either at the ends of the range of possible stimulus locations or at locations close to the point of fixation.

Recently, Steinman et al. (1997) used a line motion illusion to investigate which cue properties capture visual attention. Their data show that cues that excite the magnocellular pathway in comparison to the parvocellular pathway play a special role in capturing visual attention.

Third, 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
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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. A similar effect can be seen in the findings of asymmetric interference effects in letter detection studies. Distractors located on the peripheral side of the target interfered more than foveally placed distractors. However, Banks, Bachrach, and Larson (1977) found that some of the asymmetry in the interference effect resulted from a decline in letter visibility with eccentricity.

Conversely, when distractors are positioned in the periphery and some attention is given to equating distractor visibility to compensate for changes in resolution across the visual field, distractors located as far away as 5 [degrees] of visual angle have been found to interfere with centrally located targets (Gatti & Egeth, 1978; Goolkasian, 1997; Hagenaar & Van der Heijden, 1986; Miller, 1991). Moreover, Miller (1991), using a flanking letter task, found that the size of the interference effect decreased with increased target/distractor distance.

The extensiveness of the distance effect provides important evidence for the width of the attentional beam. The finding of a distractor effect at far locations is consistent with a visual attention mechanism that encompasses a wide attentional beam. Steinman, Steinman, and Lehmkuhle (1995), while measuring a motion illusion, described an attentional field with an excitatory center at the cued location and an inhibitory surround covering the remaining area of the visual field. They propose that, when attending to a cued location, there is an enhanced sensitivity to a small area around the cue and an inhibitory region outside the area throughout the rest of the visual field. The central mechanism is an attentional beam that functions similarly to the zoom lens model in that its size may vary with task requirements. However, the maximum size of the beam is set at 12 [degrees] to 13 [degrees] of visual angle - much wider than traditional spotlight notions (Eriksen & St. James, 1986; Posner et al., 1980). Because most attention studies limit their investigations to distance effects within a few degrees of visual angle, there are few data available to support the wide attentional beam. Steinman et al. (1995) encourage studies that investigate broader distance effects than typically used to test space-based models of attention. According to their view, distractors located anywhere within the central attentional beam (an area that may be as large as 12 [degrees] of visual angle) could influence target processing.

The purpose of this study was to test for distance effects across retinal areas. In Experiment 1, target location was fixed in the fovea while the distractor appeared at varying distances (0.6 [degrees] to 20 [degrees] of visual angle) in both an up/down and right/left direction from the target. In Experiment 2, the target was presented at varying distances from a centrally located distractor and the target location was cued 50 ms in advance. In Experiment 3, both target and distractor locations were varied such that three retinal areas were studied (foveal target/peripheral distractor, peripheral target/foveal distractor, and target/distractor at same retinal location in opposite hemifields).

The target and distractor stimuli were letters that varied in compatibility. The target letter was either an A or B, and the distractor letter was compatible (same letter as the target), incompatible (the other target letter), or neutral (a nontarget letter M). Distractor compatibility effects were measured by comparing RTs for target letters accompanied by incompatible and compatible distractors. Neutral distractors were used for comparison with incompatible distractors to measure the interference effect and with compatible distractors to measure the facilitation effect. Because it involved only a target and a single distractor letter, the task avoided some problems with the flanker task in terms of its geometry (Yantis & Johnson, 1990) and difficulty with distractors becoming reference objects (Logan, 1995). Also, because the perceptual load was low, according to Lavie (1995), the task provided the necessary condition for measuring distractor interference.

Stimulus letters were presented at varied eccentricities and their sizes were scaled to compensate for the changes in resolution across the visual field and to maintain visibility. The values used to scale the stimuli are in inverse proportion to the striate cortical magnification factor. This technique, called 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 (Virsu, Nasanen, & Osmoviita, 1987; Virsu & Rovamo, 1979).

The target and distractor letters appeared for a short duration (50 ms) and were masked following the offset of the stimulus to control the amount of time that the stimulus was visible. In Experiments 2 and 3, some of the conditions included a location cue, which appeared for 50 ms before the presentation of the stimulus letters. Across all conditions, the exposure duration was long enough to clearly process the target and distractor letters, but was shorter than the
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180-250 ms needed to initiate an eye movement (Alpern, 1971; Saslow, 1967).

There is converging evidence from the three sources cited previously (qualitative difference in foveal and extrafoveal processing, some difference in attentional gradients with eccentricity, and evidence of broad distance effects only when peripheral distractors appear with a foveal target) that suggests that the extensiveness of the distance effect would vary with retinal location. Moreover, recent evidence (Grabowska & Nowicka, 1996; Tootell, Silverman, & DeValois, 1981; Sekuler & Blake, 1994; Steinman et al., 1997) regarding the varying sensitivities of the P and the M cells to spatial frequency and other stimulus characteristics may provide a neurological explanation for the expectation of varying distance effects across retinal location.

Space-based theories typically emphasize the distance between the target and distractor stimuli irrespective of retinal location. The locations of the target and distractor may be an equally important issue. If target/distractor distance is held constant and the presentation location is varied across experiments (as in Experiments 1 and 2) and within an experiment (Experiment 3), then the effect of retinal location on the spatial distribution of attention should be evident. Although we know that participants can attend to targets placed at varied retinal locations, not much is known about what happens when participants are asked to ignore a relevant distractor. When Pan and Eriksen (1993) investigated attentional field effects with a response competition paradigm, they reported distance effects that resulted from a failure of inhibition of competing stimuli. Also, cuing studies have shown that it is easier to ignore central than peripheral cues (Juola, Koshino, & Warner, 1995) and peripheral cues have been shown to capture attention more readily than foveal cues (Jonidas, 1981).

Generalizing from these findings, distance effects may vary in Experiments 1 and 2 because of a participant’s ability to more efficiently ignore a distractor positioned in the fovea than one in the periphery. Moreover, uncertainty regarding where the peripheral distractor would appear in Experiment 1 may have made the distractor difficult to ignore. However, in Experiment 2 the consistent placement of the distractor in a central location may have made it easier to ignore.

EXPERIMENT 1

Experiment 1 tested for the broad distance effects predicted by Steinman et al.’s (1995) wide attentional beam and observed by a number of researchers when a centrally placed target is presented together with a peripheral distractor (Gatti & Egeth, 1978; Goolkasian, 1997; Hagenaar & Van der Heijden, 1986; Miller, 1991). A distractor letter was presented at several distances (ranging from 0.6 [degrees] to 20 [degrees] of visual angle) from a centrally located target letter. The target location was fixed in the center of the display and cued on every trial by a fixation point. The distractor was positioned to the right/left or above/below the target letter. Compatible, incompatible, and neutral distractor conditions were used.

Compatibility effects were expected across several distractor distances with both horizontally and vertically positioned distractors. Because the task was a low perceptual load, there was sufficient spare capacity for processing the distractor. Moreover, the distractor letters were scaled in size to maintain visibility even at the largest eccentricity. Results consistent with past literature would show compatibility effects out to at least 5 [degrees] of visual angle. Also, because the visual attentional mechanism is often thought of as circular, compatibility effects were expected to be consistent for distractors located above/below and to the right/left of the target.

METHOD

Participants

Participants in all experiments were 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, and participated to obtain credit points in a psychology class. Although the participants were volunteers from the same pool, different students participated in each of the experiments. Experiment 1 used 30 students and Experiments 2 and 3 used 60 students each. The experiments were undertaken with the understanding and written consent of each participant.

Stimulus materials
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The target and distractor letters were uppercase letters, produced from the Macintosh character set (Geneva font). Scaling the letter size involved varying points, where each point equaled 0.014 inch. The letters were printed in black against a bright background with a luminance of 121 cd/m^2. The letters were black, with a luminance of 24.30 cd/m^2. (Luminance was measured with a Minolta LS 100 luminance meter).

The target letter, either A or B, was a 7-point letter centrally located on the screen. With the participant seated 30 cm from the screen, the visual angle subtended by the letter was 0.47 [degree] in height by 0.23 [degree] in width. A distractor letter, either A, B, 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: 0.62 [degrees], 1.25 [degrees], 2.5 [degrees], 5 [degrees], 10 [degrees], and 20 [degrees] of visual angle.

Distractor letters varied in size as a function of location. Letter sizes were scaled so 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[(1 + 0.33E + 0.00007[E.sup.3]).sup.-1], where M is the cortical magnification factor and E is eccentricity in degree 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 0.97. When letter sizes are scaled in proportion to a foveal value of 7.99, the distractor was 1.21 times the target size at the nearest location and 8.17 times the target size at the farthest location. The following letter sizes were used for the scaled distractors in order of increasing eccentricity: 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 0.5 [degree], 0.67 [degrees], 0.86 [degree], 1.26 [degrees], 2.07 [degrees], and 3.88 [degrees], respectively.

The target and distractor letters were displayed on a NEC color high-resolution 19-in. 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

Figure 1 displays the events on each trial. Trial onset was automatic and began with a fixation cross (exposed for 1 s) that provided a spatial cue for the target location. Target and distractor letters followed for 50 ms. A mask terminated the stimulus event and remained on the screen until the participant made a key press response. The mask was a grating of diagonal lines (0.5 mm wide) with a luminance of 60.77 cd/m^2 that was large enough to cover the stimulus field. For the condition in which the distractors were positioned above/below the target, the mask covered a 48 [degrees] area, and for the right/left distractors, the mask covered a 15 [degrees] by 48 [degrees] area. RTs measured the time between presentation of the target letter and the key press response.

Students participated individually in a session of approximately 35 min. A chinrest 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 fixation cross and to identify the letter that appeared at that location as quickly as they could by pressing A or B on the keyboard. Each student participated in a block of 30 practice trials, and then in two blocks of 216 trials each. The blocks represented the right/left and above/below distractor conditions and were presented in counterbalanced order across participants. Within each block there was a random arrangement of the six distractor distances and the three distractor compatibility conditions (compatible, incompatible, and neutral). There were 12 replications of each of the 18 experimental conditions and within each of the 12 replications there was an equal number of distractors positioned to the right or left of the target and above or below the target.

RESULTS

Means presented in Figure 2 were computed from the correct RTs and the proportion of incorrect responses obtained from each participant across the 12 trials within each experimental condition. RTs above 1,000 ms (less than 2% of the responses) were not included in the analysis. The data from two participants were removed from the analysis because of a large number of incorrect responses. A 2 x 3 x 6 repeated-measures analysis of variance (ANOVA) was used on the RTs and the error data to test for the effects of horizontal/vertical direction, distractor compatibility, and distractor distance. The F tests reported in this experiment and in the other two experiments include the Geisser-Greenhouse correction to
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protect against possible violation of the homogeneity assumption.

Reaction times

As can been seen in Figure 2, compatibility effects varied as a function of the distractor’s distance from the centrally located target, $F(10, 270) = 6.47, p = .0001$. The size of the effect was inversely related to distance. Table 1 presents the results of post hoc comparisons (ps [less than] .05) between related and neutral distractor conditions. Response-incompatible distractors were found to significantly interfere with target processing when positioned within at least 5 [degrees] of a centrally located target. Significant facilitation effects from compatible distractors were limited to a smaller area (1.25 [degrees] of visual angle) around the target. The ANOVA on the RTs showed significant main effects of distractor compatibility, $F(2, 54) = 61.99, p = .0001$, and distractor distance, $F(5, 135) = 39.50, p = .0001$.

Distractor placement above/below or to the right/left of the target did not influence target RTs, $F$ [less than] 1; this variable did not interact with compatibility, $F$ [less than] 1; distance, $F(5, 135) = 1.03, p = .39$; or compatibility by distance, $F(10, 270) = 1.22, p = .30$.

Table 1. The distractor compatibility effect divided into interference (incompatible - neutral) and facilitation (neutral - compatible) effects

<table>
<thead>
<tr>
<th>Location</th>
<th>Compatibility effect</th>
<th>Interference</th>
<th>Facilitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.62 [degree]</td>
<td>62(*)</td>
<td>46(*)</td>
<td>16(*)</td>
</tr>
<tr>
<td>1.25 [degrees]</td>
<td>42(*)</td>
<td>31(*)</td>
<td>11(*)</td>
</tr>
<tr>
<td>2.5 [degrees]</td>
<td>33(*)</td>
<td>24(*)</td>
<td>9</td>
</tr>
<tr>
<td>5.0 [degrees]</td>
<td>31(*)</td>
<td>23(*)</td>
<td>8</td>
</tr>
<tr>
<td>10 [degrees]</td>
<td>15(*)</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>20 [degrees]</td>
<td>8</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Experiment 2: precue condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.62 [degree]</td>
<td>40(*)</td>
<td>17(*)</td>
<td>23(*)</td>
</tr>
<tr>
<td>1.25 [degrees]</td>
<td>20(*)</td>
<td>0</td>
<td>20(*)</td>
</tr>
<tr>
<td>2.5 [degrees]</td>
<td>12</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>5.0 [degrees]</td>
<td>16(*)</td>
<td>17(*)</td>
<td>-1</td>
</tr>
<tr>
<td>10 [degrees]</td>
<td>1</td>
<td>9</td>
<td>-8</td>
</tr>
<tr>
<td>20 [degrees]</td>
<td>2</td>
<td>9</td>
<td>-7</td>
</tr>
<tr>
<td>No precue condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.62 [degree]</td>
<td>37(*)</td>
<td>24(*)</td>
<td>13</td>
</tr>
<tr>
<td>1.25 [degrees]</td>
<td>18(*)</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>2.5 [degrees]</td>
<td>14(*)</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
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<td>0</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>10 [degrees]</td>
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</tr>
<tr>
<td>20 [degrees]</td>
<td>9</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

* p [less than] .05.

Errors

Unlike the RT data, the ANOVA on the error data showed a three-way interaction of the horizontal/vertical direction, distractor compatibility, and distance, $F(10, 270) = 3.17, p = .004$. The triple interaction results from a tendency for incompatible distractors to interfere with target processing across a broader distance with horizontally positioned distractors as compared with vertically positioned distractors. When the distractors appeared to the right or left of the target, incompatible distractors caused more errors than other distractors when they were presented within at least a 5 [degrees] area around the target; when distractors appeared above or below the target, interfering effects of incompatible distractors were apparent to at least a distance of 2.5 [degrees] of visual angle. Compatibility effects were also found to
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vary by distance, $F(10, 270) = 10.82, p = .0001$. More errors were made when incompatible distractors were presented as compared to the other distractor conditions and when the incompatible distractors appeared closer to the centrally located target.

The ANOVA showed main effects of compatibility, $F(2, 54) = 19.80, p = .0001$, and distance, $F(5, 135) = 25.82, p = .0001$, but no effect of direction, $F(1, 27) = 1.27, p = .27$. Moreover, direction did not interact with compatibility, $F \text{ [less than] 1}$, or distance, $F(5, 135) = 1.75, p = .14$.

DISCUSSION

These results show distractor compatibility effects extending out to 10 [degrees] of visual angle when participants are attending to a target letter that appears consistently in the center of the visual field. Table 1 identifies the boundaries for the attended area by measuring the size of the interference and facilitation effect across a number of eccentricities. These findings are consistent with the prediction of Steinman et al.’s (1995) wide attentional beam and with a number of other studies that show that distractors positioned at some distance from a target can interfere with processing. Also, in accord with past findings (Goolkasian, 1997; Miller, 1991), the size of the compatibility effect was found to decrease with increasing target/distractor distances.

The results confirm the presence of broad distance effects when scaled letter distractors are presented in a low-load task and measure the boundary for the attentional area. Distractors positioned at 20 [degrees] of visual angle were not found to affect target processing. Also, the consistency of the distractor effect, irrespective of horizontal or vertical distance from the target, supports the circular nature of the attentional area. However, there was an effect of distractor direction, evident with the error data. Broader distance effects with horizontally located distractors may result from some difference in resolution between horizontally and vertically positioned distractors.

EXPERIMENT 2

In Experiment 2, a target letter appeared at varying distances (0.6 [degrees] to 20 [degrees] of visual angle) from a centrally located distractor letter. Target/distractor distances were the same as in Experiment 1; the only difference was the switch in the presentation location of the target and distractor letters and the addition of a bar marker to cue the target location. However, as in Experiment 1, when the fixation cross cued the target location, the cue predicted the target location on every trial. This paradigm was modeled on one introduced by Yantis and Johnson (1990) to promote effective allocation of attention and to provide incentive for the participants to focus attention on the target location. However, the current experiment used a shorter precue exposure duration than the ones used by Yantis and Johnson (1990) to prevent eye movements toward the cued location. Cuing has been successfully demonstrated with short precue exposure durations (Eriksen & St. James, 1986; Murphy & Eriksen, 1987).

Two cue conditions were tested: Precue (the cue appeared 50 ms before the stimulus display) and No Precue (cue presented simultaneously with the stimulus display). The cue conditions were included because a number of studies have reported that distractor processing varies in response to precue conditions. When the target position is known in advance, RTs are shorter (Johnson & Yantis, 1995), there is a decrease in distractor compatibility effects (Fox, 1995; Paquet & Lortie, 1990), and Fournier (1994) suggested that precuing target location influences distractor processing because it helps to perceptually segregate the target from the distractor information.

As in Experiment 1, the purpose of this study was to test for distractor compatibility effects across varied target/distractor distances. Because attention was focused on a target located in the visual periphery, rather than in the fovea, distractor effects were not expected to extend across the far locations, as in Experiment 1. Results consistent with previous work (Goolkasian, 1981) would show compatibility effects only for targets located near the centrally located distractor. Also, the consistent placement of the distractor at the foveal location should make it easy to ignore.

METHOD

The stimulus materials were the same as in Experiment 1 except that the distractor letter was the 7-point letter centrally located and the target letter varied in size as a function of location. As indicated in Figure 1, a bar marker was used to cue the target location. The bar marker was a black line positioned adjacent to the target location. When the target was
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located above/below the distractor, the bar marker viewed at a distance of 30 cm covered an area of 0.95 [degree] x 0.38 [degree] of visual angle and was positioned to the left side of the target location. When the target appeared to the right/left of the distractor location, the bar marker (0.38 [degree] 0.95 [degree]) was positioned below the center of the target location.

The trial began when a fixation cross was displayed for 1 s. On the Precue trials, the bar marker followed for 50 ms and then the target and distractor letters were superimposed on the display for an additional 50 ms. A mask terminated the stimulus event and remained on the screen until the participant made a key press response. On the No Precue trials, the bar marker appeared simultaneously with the target and distractor letters and remained on the screen for 50 ms, followed by the mask.

The participants were randomly divided between the Precue and the No Precue conditions (30 in each condition). They were instructed to keep their eyes on the fixation cross and to identify the target letter that appeared at the location adjacent to the bar marker as quickly as they could by pressing A or B on the keyboard. As in Experiment 1, each participant had a block of 30 practice trials and then two blocks of 216 trials each. There were 12 replications of the experimental conditions and within each condition there was an equal number of targets positioned to the right or left of the distractor and above or below the distractor. In all other respects, this experiment was similar to the first.

RESULTS

A 2 x (2 x 3 x 6) ANOVA was used on the RTs and the error data to test for the between-subject effect of cue condition and the within-subject effects of horizontal/vertical direction, distractor compatibility, and target distance. RTs longer than 1,000 ms (less than 2% of the responses) were not included in the analysis.

Reaction times

As in Experiment 1, compatibility effects varied with the target/distractor distance, F(10, 580) = 4.04, p = .0001. Figure 3 presents the interaction of distractor compatibility by target distance by cue condition even though cue condition was not found to interact with distractor compatibility and distractor location, F (10, 580) = 1.76, p = .08. Compatibility effects were most evident for targets presented near the centrally located distractor. Post hoc comparisons in Table 1 show significant interference from incompatible distractors only when the participants were attending to targets located within 1 [degree] of visual angle. When attention was focused on targets positioned at more distant eccentricities, there was little interference. (There was one exception to the previous statement. For targets located at 5 [degrees] when a precue was present, incompatible distractors produced some interference on target latencies. This finding did not occur when targets appeared at closer locations or when the precue was not present.) As in Experiment 1, significant facilitation effects from compatible distractors were observed when attending to targets located anywhere within at least a 1.25 [degrees] area but only when a precue was present. However, the absence of a facilitation effect in the No Precue as compared to the Precue condition was not a strong enough difference for a significant interaction of cue by distractor compatibility by location. As expected, there were significant main effects of larger location, F(5, 290) = 92.93, p = .0001, and distractor compatibility, F(2, 116) = 31.02, p = .0001.

RTs to targets placed above/below the distractor were longer than for targets placed to the left or right, F(1, 58) = 12.82, p = .0007. (The means for these conditions are 486 and 465 ms, respectively.) The difference between horizontal/vertical direction increased in direct relationship with eccentricity, F(5, 290) = 16.52, p = .0001. Also, the elevation in target latencies that is apparent from Figure 3 at the two largest eccentricities was caused primarily by the targets positioned at some vertical distance from the distractors. Such an elevation was not found when targets were presented to the right or left side of the distractor.

Precue effects were found to vary with target distance, F(5, 290) = 12.99, p = .0001. AS expected, target latencies were shorter when the participants were warned in advance where the target would appear than when the cue appeared at the same time as the target, and the cued effect became stronger with increasing eccentricity. However, the cue conditions did not influence the distractor compatibility effect, F [less than] 1, nor was there a main effect of the precue, F (1, 58) = 1.43, p = .23.

Errors
Precue effects were more apparent in the error data than the RT data. The ANOVA showed that compatibility effects varied by target distance, \( F(10, 580) = 5.25, p = .0001 \), and by target distance and cue condition, \( F(10, 580) = 2.55, p = .01 \). As shown in Figure 3b and 3d, there were more errors in target responding when the incompatible distractors were presented with targets positioned within at least a 1.25 [degrees] of visual angle than in any other condition. Also, the triple interaction with cue condition appears to be caused by a somewhat larger error rate at the near target location with a precue than without one, and a small elevation in the error rate when targets appeared at the largest eccentricity with related distractors as compared to neutral distractors. That elevation was apparent only in the No Precue condition. There was a main effect of compatibility, \( F(2, 116) = 17.39, p = .0001 \), and target distance, \( F(5, 290) = 8.38, p = .0001 \).

There was no main effect of cue condition, \( F(1, 58) = 2.92, p = .09 \), but this variable interacted with target location, \( F(5, 290) = 8.38, p = .0001 \), and compatibility, \( F(2, 116) = 17.39, p = .0001 \). Error rate was higher at the near target location when the precue was present than in the other condition. Also, with the precue there were more errors with incompatible distractors than without the precue.

Horizontal/vertical direction of the target placement was not found to influence the error rate, \( F [less \ than] 1 \), nor did this variable interact with any of the others.

**DISCUSSION**

Centrally located distractors interfered with target processing primarily when the targets were located within 1 [degree] of visual angle. Unlike the results of Experiment 1, strong distractor compatibility effects were apparent only for near targets. Although significant effects were measured at more distant target locations, the compatibility effects were weak in comparison to the findings of Experiment 1. These results are consistent with previous work (Goolkasian, 1981), which showed that a centrally located distractor interfered only with near targets and with asymmetric interference effects of letter distractors presented centrally to the target. Also in contrast to the first experiment, these results support the traditional spotlight theory of attention, which suggests that focusing attention on an area in the visual field sensitizes a circular area of about 1 [degree] of visual angle around the target (Posner et al., 1980) rather than supporting the notion of a wide attentional beam, as suggested by Steinman et al. (1995).

Precuing the target location had the anticipated effect of decreasing target latencies and the RT advantage became more evident with increasing target eccentricity; however, it did not have a major influence on the distractor compatibility effect. Table 1 shows that in the No Precue condition the compatibility effect extends across a broader distance than in the Precue condition. However, the effect was not strong enough to be significant. Cuing effects were more evident with the error data than with the RTs. Precuing the target location increased the error rate associated with incompatible distractors positioned near the targets, and in the absence of the precue, related distractors increased the error rate in comparison to neutral distractors when attention was focused on far targets.

There are a number of reasons why cuing effects might not have been as evident in these findings as they were in previous studies (Fox, 1995; Paquet & Lortie, 1990). First of all, most previous studies (Fox, 1995; Paquet & Lortie, 1990) used a centrally located target and cue. In the current experiment, the extrafoveal placement of the target together with variation in its location on each trial represented a very different presentation condition than the one used in previous work. Also, the use of a short precue exposure duration to minimize the possibility of an eye movement toward the target location may have explained the difference. Another possibility is that the manipulation of the cue conditions as a between-subject variable may have reduced its influence relative to some of the other variables that were studied.

Whether the target was displaced horizontally or vertically with respect to the distractor was found to influence target latencies. RTs were shorter when the targets appeared to the right or left of the distractors and the effect became larger with increasing target/distractor distance. Although others (Schaller & Dziadosz, 1975) have found asymmetries in target detection with horizontal and vertical placement of stimuli, there is no well-accepted explanation. These data support the hypothesis that visual resolution may drop off more quickly above and below than to the right or left of a target. However, despite the effect of direction on overall target latencies, it did not influence the compatibility effect. Effects of distractor compatibility across several eccentricities were the same whether the target appear above/below or to the right/left of the centrally located distractor.
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Experiment 3 also tested for distractor compatibility effects across varied target/distractor distances; however, in this experiment, retinal location of target and distractor stimuli was manipulated in (one of three ways. The target appeared in the fovea with a distractor at some peripheral distance, the distractor appeared in the fovea with a target at some peripheral distance, and both target and distractor letters appeared in the periphery at symmetric locations in opposite hemifields. The first two conditions essentially replicate the presentation conditions used in Experiments 1 and 2, with two significant differences. First, in the present experiment target and distractor locations vary on each trial and only the target location was cued. This was a change from Experiment 1, in which the target location was fixed, and from Experiment 2, in which the target location varied but the distractor location was fixed. Constancy of either the target or the distractor location may have enhanced the participant’s ability to selectively attend to the target and ignore the distractor. Other researchers (Miller, 1991) have found such effects.

Second, in Experiments 1 and 2, target processing varied with the size of the stimulus letters. In Experiment 1, the target letter was always the smaller stimulus, and in Experiment 2, the target letter was always the larger stimulus. In the current experiment, both target and distractor letters are scaled in size in accord with their presentation location and the presentation location of each varies from trial to trial. The current experiment eliminates size of the stimulus and constancy of presentation location as potential explanations for the findings.

The condition in which both target and distractor stimuli are presented at extrafoveal locations was included to measure spatial distribution of attention across hemifields. Some have suggested that covert attention is bounded by hemifields such that attention to an extrafoveal location sensitizes other locations in the same hemifield and inhibits stimulus processing in the opposite hemifield (Hughes & Zimba, 1985). Furthermore, Downing and Pinker (1985) report higher response latencies for nonattended stimulus locations across the vertical meridian than for nonattended locations at the same distance within the same hemifield. However, Henderson and Macquistan (1993) provide evidence that visual attention is not bounded by either vertical or horizontal meridians.

Because Experiments 1 and 2 did not find compatibility effects at the largest eccentricity (20 [degrees] of visual angle), the range of target/distractor distance in the present experiment was limited to 10 [degrees] of visual angle. Also, direction of the target/distractor distance was eliminated as a variable because compatibility effects were not found to vary by direction in Experiments 1 and 2. Only horizontal distance was used in the present experiment. In all other respects this experiment was similar to Experiment 2.

METHOD

For the retinal location conditions in which the target or the distractor was centrally located, the stimulus materials were the same as in Experiments 1 and 2. In the third retinal location condition, the target and distractor letters were presented at the same peripheral location in opposite hemifields. Thus, the center-to-center distances between the target and distractor letters crossed the fovea. New values of M were needed to equate the target/distractor distance with the other two retinal location conditions. These values were in order of increasing eccentricity: 7.25, 6.63, 5.65, 4.37, and 3.00. The scaled letter sizes corresponding to these values were 8, 8, 10, 13, and 19, respectively. For all three retinal location conditions, the target/distractor distances were 0.62 [degree], 1.25 [degrees], 2.50 [degrees], 5 [degrees] and 10 [degrees] of visual angle, as measured by the center-to-center distance between the stimulus letters.

The procedure on each trial was the same as in Experiment 2. On the Precued trials, the bar marker followed the fixation cross for 50 ms and then the target and distractor letters were superimposed on the display for an additional 50 ms. On the No Precue trials the bar marker appeared together with the target and distractor for 50 ms. In both conditions a mask terminated the stimulus events and remained on the screen until the participant made a key press.

The participants were randomly divided between the Precue and No Precue conditions (30 in each condition). They were instructed to keep their eyes on the fixation cross in the center of the screen and to identify the letter appearing above the bar marker as quickly as they could. Each participant received 30 trials as practice and then 540 trials. These trials represented 12 replications of the 45 experimental conditions and within each of the 12 replications there were an equal number of letters presented to the right or left of the fixation point. Within the experimental trials, there were random arrangements of the three distractor compatibility conditions, five target/distractor distances, and three retinal location conditions. In all other respects, this experiment was similar to Experiment 2.
RESULTS

A 2 x (3 x 3 x 5) ANOVA was used on the RTs and the error data to test for the between-subject effect of cue condition and the within-subject effects of distractor compatibility, retinal location, and target/distractor distance. RTs longer than 1,000 ms (less than 2% of the responses) were not included in the analysis.

Reaction time

As in Experiments 1 and 2, RTs varied as a function of distractor compatibility and target/distractor distance, F(8, 464) = 5.33, p = .0001; however, in this experiment the two-way effect also interacted with retinal location, F(16, 928) = 3.65, p = .0001. Figure 4 presents the triple interaction. To better understand how compatibility effects varied by distance under each of the retinal location conditions, follow-up comparisons tested for simple interaction effects at each of the retinal locations. In the conditions with peripheral targets (foveal distractor/peripheral target and peripheral target/distractor in opposite hemifield) [ILLUSTRATION FOR FIGURE 4b and 4c OMITTED], there were significant compatibility by distance effects as well as main effects of compatibility and target/distractor distance (ps [less than] .01). In the condition with the foveal target/peripheral distractor [ILLUSTRATION FOR FIGURE 4a OMITTED], the compatibility effect was not found to significantly vary across distance, F(8, 464) = 1.91, p = .07; however, this analysis did show significant main effects of compatibility and target/distractor distance, (ps [less than] .01).

Retinal location differences are evident in the nature of the compatibility effects across distance, as can be seen in Figure 4. In Figure 4a, with targets appearing at the fovea, strong compatibility effects are evident from peripheral distractors even when they appear at a distance of 10 [degrees] from the target. Except for a facilitation effect from a compatible distractor positioned near a target, the compatibility effect results almost exclusively from an interference from the incompatible distractors. Strong interference from peripheral distractors is also apparent when the stimuli appear in opposite hemifields [ILLUSTRATION FOR FIGURE 4c OMITTED], but the effect is limited to an area of at least 2.5 [degrees] of visual angle and the interference effect is absent at the near distance. In Figure 4b, however, distractor interference effects occur primarily to targets positioned within a degree of visual angle. Foveally presented distractors positioned at a far distance from targets have either no or weak effects on target processing. Interference effects present for near targets disappeared for targets at 1.25 [degrees] but reappeared for targets located at 2.5 [degrees] and 5 [degrees] of visual angle and disappeared again at 10 [degrees].

Precue conditions did not have much influence on target processing. The ANOVA showed that the only effect was a marginally significant interaction of cue condition by target/distractor distance by retinal location, F(8, 464) = 1.93, p = .06. The cued effect obtained in Experiment 2 of shorter RTs with Precue than No Precue was also characteristic of these data; however, the benefit with increasing target/distractor distance was obtained only in the retinal location condition with the foveal distractor and peripheral targets. In the other two retinal location conditions, the small benefit of precuing the target location remained consistent across target/distractor distance. There was no main effect of cue conditions, F(1, 58) = 1.68, p = .20, and there were no interactions of cue condition with distractor compatibility, F [less than] 1; retinal location, F [less than] 1; target/distractor distance, F [less than] 1; retinal location by compatibility, F(4, 232) = 1.34, p = .26; compatibility by location, F(8, 464) = 1.57, p = .14; or retinal location by compatibility by location, F(16, 928) = 1.04, p = .40.

The ANOVA also showed significant main effects of retinal location, F(2, 116) = 9.14, p = .0003; distractor compatibility, F(2, 116) = 101.21, p = .0001; target/distractor distance, F(4, 232) = 25.27, p = .0001; and interactions of retinal location by compatibility, F(4, 232) = 2.93, p = .02; retinal location by target/distractor distance, F(8, 464) = 14.61, p = .0001.

Errors

Retinal location condition was also found to have a significant influence on response errors. More errors were made when the target appeared in the fovea than with peripherally presented targets, F(2, 116) = 12.19, p = .0001. (Means for these two conditions are respectively 9.6% and 7.6%.) Retinal location condition interacted with target/distractor distance, F(8, 464) = 2.85, p = .0007; and with target/distractor distance by compatibility, F(16, 928) = 5.31, p = .0001. This analysis also showed a significant main effect of distractor compatibility, F(2, 116) = 49.56, p = .0001.

Follow-up comparisons tested for the simple interaction effects of distractor compatibility by target/distractor distance at
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Each of the three retinal locations. The findings were similar to the results with the RT data. Compatibility effects varied by target/distractor distance in the two retinal location conditions with peripheral targets, (ps [less than] .05); however, with a foveal target compatibility effects were consistent across retinal location, $F(8,464) = 1.81$, $p = .09$.

The pre cue conditions were not found to influence the error rate, $F(1, 58) = 1.69$, $p = .20$, nor did this variable interact with any of the other variables.

DISCUSSION

These findings are consistent with the results of Experiments 1 and 2 in showing that distractor compatibility effects vary not only in association with the distractor’s distance from the target but also in association with the retinal location of the target and distractor stimuli.

Figures 4a and 4d show that foveal target processing is slowed by the presence of an incompatible distractor that appears at least out to a 10 [degrees] area to the right or left of the fixation point. As in Experiment 1, these results support the concept of a wide attentional beam (Steinman et al., 1995). Unlike the data from Experiment 1, however, the compatibility effect was not found to decrease with increasing target/distractor distance.

Figures 4b and 4e show that when attending to a target located in the visual periphery, a foveally placed distractor interferes primarily when it appears near the target. Targets positioned at eccentricities greater than 1 [degree] of visual angle are not strongly influenced by foveally placed distractors. There were minor differences between the findings in this retinal location condition and the results of Experiment 2. The effects of the centrally located incompatible distractor disappeared when targets were located at 1.25 [degrees] but reappeared at other far locations. It may have been easier for participants in Experiment 2 to ignore relevant distractors than for the participants in Experiment 3 because the distractors were always located at the same place. Varying the distractor location may have made them more difficult to ignore.

In contrast to these findings, however, Figure 4c and 4f show compatibility effects when distractors appear at the same eccentricity in the opposite hemisphere from the target. Strong compatibility effects are present at least out to an area of 2.5 [degrees] of visual angle. Interestingly, although participants were able to ignore foveal distractors when positioned far from the target, they could not ignore distractors that appeared at the same location in the opposite hemifield. This finding is consistent with those of Henderson and Macquistan (1993), who showed that attention was not bounded by the vertical meridian. It is possible to attend to stimulus letters presented in opposite hemispheres. This finding suggests that retinal location of the target is not the only determining factor in obtaining a distractor compatibility effect. It appears that retinal location of the distractor is also an important variable. Distance effects are obtained across a wider area when distractors are positioned in the visual periphery rather than at fixation. This finding may indicate an ability to control foveal processing more effectively than peripheral processing. It may be that participants can attend to or ignore a foveal event more effectively than a peripheral event.

As in Experiment 2, precuing target location was not found to influence the compatibility effect across target/distractor distance. This finding is in contrast to those of Fox (1995) and Paquet and Lortie (1990), who show that precuing target location increases attentional selectivity and decreases the effect of incompatible distractors. However, as indicated in the discussion section of Experiment 2, there were a number of differences between this experiment and the previous work. For example, Fox (1995) used a procedure similar to that of Yantis and Johnson (1990), with a long precue (150 ms), and when the precue exposure duration is added to the 50 ms for the target display there may have been enough time for an eye movement toward the target location. Eye movements were precluded in this experiment by the brief precue and target durations and by masking of the target display. Paquet and Lortie (1990) used a flanker paradigm and target location was consistently in the middle. Their cue was the presence and absence of the fixation point. However, if the target was always the middle letter, then the only purpose of the fixation point was to predict when the target would appear rather than where it would appear. Also, the use of a foveal target made it very different from the cued locations used in the current experiments.

Because these findings are consistent with the pattern of distance effects observed in the first two studies, it is unlikely that the size of the stimulus could provide a viable explanation for the findings. In the current experiment, the size of the stimulus varied randomly with the presentation location of the target and distractor stimuli. However, it is unlikely that even
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In Experiments 1 and 2 the size of the stimulus influenced the distance effects. Were that the case, compatibility effects would have increased in direct proportion to the size of the stimulus letters; instead, the results were consistent with Miller’s (1991) in showing a compatibility effect that was inversely related to target/distractor distance.

GENERAL DISCUSSION

The findings of these experiments when taken together show that retinal location is an important variable for explaining target and distractor processing. Distance effects of related distractors on target processing were not homogeneous across retinal location. Experiments 1 and 3 showed effects of related distractors positioned anywhere within a 10 [degrees] area around a foveal target and interfering effects of the distractor are strong whether the target location is constant or varies from trial to trial. These findings extend the previous work (Gatti & Egeth, 1978; Goolkasian, 1997; Hagenaar & Van der Heijden, 1986; Miller, 1991) showing broad distance effects by identifying the boundaries for the interfering and facilitating effects of the distractor. They also provide evidence for Steinman’s space-based theory of attention showing a broad spotlight.

However, the pattern of findings changes when the same target/distractor distances are studied, but the presentation locations of the target and distractor letters are switched, as in Experiments 2 and 3. Distance effects of related distractors are observed primarily on targets located near the foveal distractors. When distractor location is varied (Experiment 3) rather than constant (Experiment 2), some compatibility effects are evident with far target locations, but the effects are small in comparison to the compatibility effects obtained at the other retinal location conditions. The pattern of findings is consistent with some classic studies showing distractor effects limited to near targets and to traditional spotlight notions of attention (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1972).

In light of the current evidence, it appears that the controversy over the variation in distractor compatibility effects across target/distractor distance, with some studies showing distractor effects at far locations and others showing effects limited to a small area around the focal point, may be explained partially by retinal location differences in target/distractor presentation conditions.

Most interesting of all are the distance effects obtained when the stimuli appeared at the same retinal location in opposite hemifields. Strong compatibility effects are found for stimuli presented within a 1 [degrees] to 2.5 [degrees] area. These data are not consistent with theories that the attentional area is limited to locations within the same hemifield (Hughes & Zimba, 1985); instead, they suggest that at some extraneous locations the focal area associated with attention to stimuli may include the same retinal location in the opposite hemifield. It appears that when covert attention is focused on a stimulus located on one side of the functional visual field, information presented at the same retinal location in the opposite hemifield is also processed. This finding is the strongest evidence for the hypothesis that the underlying process that explains these data may reflect an inability to ignore peripheral events. The fact that the interference effect is absent when the peripheral stimuli are near may indicate an ability to control foveal events more effectively than peripheral events. Moreover, when the distractor is foveal, as in Experiment 2 or Experiment 3 (foveal distractor/peripheral target), participants are able to ignore it except, of course, when there is obvious attentional leakage, as in the weak compatibility effects observed on the far target in Figure 4b. In comparison, peripheral distractors are more difficult to ignore.

This interpretation makes sense when taken in conjunction with the results of cuing studies, which have shown that cues differ in effectiveness as a function of their location. Peripherally located cues are particularly effective at capturing attention when compared to foveal cues (Juola et al., 1995) and cues that activate the magnocellular system capture visual attention more readily than cues that activate the parvocellular system (Steinman et al., 1997). A similar mechanism may explain why the results of these experiments show that foveally placed distractors are easier to ignore than distractors positioned at varied eccentricities. The distractors used in these experiments can be considered cues because they vary in compatibility to the target and in some conditions provide information about the target response. More research is needed, however, to clarify exactly how cues for location and target content vary in effectiveness depending on where they are located in the visual field.

In essence, fundamental differences between the P and the M cells associated with foveal and extrafoveal locations are the most likely explanation for the retinal location differences observed in these studies. Also, the fact that the compatibility effect decreased with increasing eccentricity (Experiment 1) and was found to be limited to an area of at least 2.5 [degrees] of visual angle (Experiment 3 peripheral/peripheral condition) supports the argument of an underlying...
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neurological explanation for the findings. Tootell et al. (1981) found that, when recording from cells in Area 17, sensitivity to high spatial frequencies is limited to an area smaller than 5 [degrees] eccentricity, whereas sensitivity to low spatial frequencies was observed to be widely distributed (36 [degrees] of visual angle) (Grabowska & Nowicka, 1996; Tootell et al., 1981). Because letter distractors require high spatial frequency analysis for processing, such a finding would explain why letter distractors lose their interfering effect at large eccentricities. Scaling the letter size obviously helps to mitigate this effect but probably does not eliminate it.

For some time we have been talking about the variation in the size of the attentional beam with perceptual load. The zoom lens model has received a good deal of empirical support (Eriksen & St. James, 1986; Lavie & Tsal, 1994). Perhaps there is a similar variation in the size of the attentional beam with regard to retinal location. In these studies the absolute distance between the target and distractor (as measured in degrees of visual angle or eccentricity) was held constant while the retinal location of the target and distractor stimuli was varied. The effects of the related distractor on target processing varied as a function of retinal location. Distractor effects at far distances were obtained with foveally presented targets and extrafoveal distractors. When distractors appeared at the fovea, interference effects were obtained primarily in response to near targets. The typical assumption of space-based theories of attention that distance effects occur irrespective of retinal location may not be accurate.

Notes

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