

SHIFTS OF COVERT VISUAL ATTENTION: A FUNCTION OF MERIDIA, DISTANCE, AND CUE TYPE

MELI MACCURDY

Abstract:

Shifts of covert attention differ depending on whether the shift is exogenously or endogenously motivated. The present study examined whether crossing imaginary meridians in the visual field influences shifts directed by central or peripheral cues. A two-alternative forced-choice discrimination task was employed under direction from 70 % valid central and peripheral cues. In comparison to central cues, peripheral cues produced greater benefits in response time and accuracy when valid, and greater costs in response time and accuracy when invalid. In both cue types distance was the most prominent factor in RTs and accuracy. Meridians were also found to be significant in both cue types, and crossing a horizontal meridian took more time than crossing a vertical meridian. The most parsimonious account for these data in both cue types is a general specific location model of attention, with strong support for a gradient theory from the central cue paradigm.

Introduction

Since Helmholtz (1866) and James (1890) it has been clear that humans can shift attention from one location to another without making overt eye movements. These covert shifts of attention take time, the amount of which is a complex function of the type of stimulus (Shaw, 1984), task difficulty (Eriksen & St. James, 1986; Eriksen & Yeh, 1985; LaBerge, 1983), presence of cue (e.g., Posner, Snyder, and Davidson, 1980), type of cue (Jonides, 1981), and distance traversed (e.g., Downing & Pinker, 1985; Henderson, 1991; Egly & Homa, 1991; Shulman, Remington, and McLean, 1979). Various general hypotheses attempt to account for how these factors interact in the movement of attention, differing primarily by the amount of space attention fixates on. General region hypotheses argue that whole regions of space are attended to and not specific target areas. Conversely, specific-location hypotheses argue that points in space (often the size of targets) receive a narrow focus of attention.

Hughes and Zimba's meridian boundary model is a principal argument for a general region hypothesis of attention. These authors argue that attention is bounded by entire hemifields separated by a vertical meridian (1985) or specific quadrants bounded by both vertical and horizontal meridians (1987). The primary claim Hughes & Zimba make based on their experiments is inhibition of the unattended hemifield or quadrants, with no strong benefits of targets in the attended hemifield. They found that moving visual attention across a vertical meridian takes more time than crossing a horizontal meridian, but less time than crossing both meridians (i.e., when attention is moved to diagonally located quadrants). Further studies support the meridional effect that drives Hughes & Zimba's arguments (e.g., Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987; Downing and Pinker, 1985; Rizzolatti, Riggio, Dascola, & Umiltà, 1987).

The specific location hypothesis was first described as a moving spotlight with a narrow focus of fixed attentional resources (e.g., Posner, Snyder, and Davidson, 1980; Shulman, Remington, and McLean, 1979; Tsai, 1983) and later as a zoom-lens with variably diffuse resources (e.g., Eriksen and Yeh, 1985; LaBerge, 1983; Eriksen and St James, 1986; Eriksen and Webb, 1989). Targets falling within this location (valid cues) are quickly responded to, while responses to targets not appearing within a cued location (invalid cues) take longer. According to the spotlight model, the quicker responses to validly cued targets are due to the narrowly focused beam of attention already located at the target location, while slower responses to invalidly cued targets result from analog movements of this beam's attentional resources to the target area. While the spotlight model assumes that attention is fixated on a particular location discretely bounded by the circumference of the beam, the zoom-lens model accounts for a different "resolving power"

(i.e., diameter of the beam) strategically controlled by the attender depending on the task situations. In the zoom-lens model the intensity of the beam is inversely related to the diameter of the beam. If the cued region is larger, the illuminated area of the spotlight is also larger, though more diffusely distributed. The zoom-lens model therefore includes a two-part explanation for attending to targets in cued location: one includes task factors, which initially determine the size of the lens; the other is relevant when attention shifts large enough distances that the whole lens moves in an analog fashion toward the target location.

A gradient theory (Downing, 1988; Downing and Pinker, 1985; Henderson, 1991; LaBerge and Brown, 1989) is a combination of both specific-location and general region models. While it claims that attention centers around specific locations, it also includes a distribution of attentional resources surrounding this fixation. However, while the quadrant model claims that this distribution is diffuse between discrete boundaries, gradient theories include many factors for this distribution. Additionally, while the zoom-lens model partially attributes the shape of the lens to subjective control, gradient theories argue that the attentional distribution is entirely determined by cortical mapping of the given task demands and retinal eccentricity of the display. Gradient models account for longer response times with increasing distance, but not by appeal to analog movements like the spotlight and zoom-lens models. Target locations of increasing distances from the cued location take more time to attend to, but not because attention is shifted there, *per se*, as analog spotlight models contend. Instead, longer response times result from the fact that these locations simply have fewer attentional resources already allocated to them. It is also important to note that gradient models demarcate between retinal eccentricity (Tsal, 1983) and cortical mapping, where the former is the topography of the retina and the latter is how this is represented in cortex.

Any of these theories for covert shifts of attention must contend with three more general phenomena. First, an adequate theory must account for the cost-benefit analysis, where valid cues have antipodal effects to invalid cues. Second, a theory must account for shifts of both the exogenous and endogenous covert attentional systems. A third, potential phenomenon is the effect of general barriers in the visual field that shifts of attention must maneuver around.

The cost-benefit analysis is a description of the fact that invalid cues produce longer target responses than no cue (costs), and valid cues facilitate faster correct responses than no cue (benefits) (Posner, Snyder, & Davidson, 1980). Studies supporting the general region hypothesis find either no benefits of valid cues (Hughes & Zimba, 1985), or at least report an incongruence between invalid (large costs) and valid (very small benefits) cues (Hughes & Zimba, 1987; Tassinari et al., 1987). The inability of these studies to represent the cost-benefit model poses a legitimate concern for the validity of their main findings (See Klein and McCormick, 1989 and McCormick & Klein, 1990, for this and other concerns with Hughes & Zimba's experimental paradigm).

The acknowledged lateralization of the visual system could feasibly present some sort of barrier—either a wall or a peak—to shifting attention from one hemifield to another. Studies in brain damaged patients who show neglect (Posner, Walker, Friedrich, & Rafal, 1984), split brain syndrome (Gazzaniga, 1985; 1995), and other specific unilateral lesions (Petersen, Robinson, Morris, 1987) indicate that people process and attend to information in brain hemispheres contralateral to visual hemifields. Kinsbourne (1987) and Reuter-Lorenz, Kinsbourne, and Moscovitch (1990) also provide rationale for vertical meridian effects.

The above neurophysiological evidence could support the meridian effects reported in some papers (Hughes & Zimba; Tassinari, et al., 1987; Rizzolatti, et al, 1987; Downing & Pinker, 1985). However, all of these studies are confined to what is likely one of two main classes of attention, the endogenous system. A substantial body of evidence suggests that the endogenous system is markedly different from the exogenous system. These two systems exhibit different magnitudes of the cost-benefit relationship and direct attention with different patterns. In fact, attempts to grossly explain all shifts of attention without specifically considering the differences between these systems are incomplete at best.

Jonides (1981) used central cues (an arrow at fixation point) versus peripheral cues (a flash of light directly adjacent to the target location) to invoke the endogenous versus exogenous system, respectively. In a series of experiments, Jonides investigated how central versus peripheral cues impacted three properties of target identification: capacity, resistance to suppression, and expectancy.

Jonides measured capacity as a function of task difficulty. Participants were presented with both a visual search task and a memory task simultaneously. When the memory task was fairly easy, both cue types produced strong costs and benefits of locating targets. As the memory task became more difficult, however, costs and benefits were only produced by peripheral cues. Resistance to suppression is a measure of how difficult a given cue is to ignore. In Jonides' study peripheral cues were far more resistant to

suppression than central cues, suggesting that subjects can decide whether or not to utilize central but not peripheral cues. Jonides' third category, expectancy, is a measure of whether participants can actualize their knowledge of a given cue's reliability. Central cues appear to capture participants' attention less strongly when reliability decreases, whereas peripheral cues are equally effective at any level of reliability. Thus, the mere presence of peripheral cues is enough to capture attention even when they are not reliable.

Taken together these results support Jonides' argument that peripheral cues are a more automatic mechanism of attention allocation than central cues are. Peripheral cues are more effective in directing attention than central cues, and are also more difficult to ignore and disengage from. As the task difficulty increases, maximum benefits result from the automatically capturing effects of peripheral cues. Likewise, this automaticity can be detrimental because it strongly captures participants' attention. We see, then, that central cue paradigms are more likely to allow some subjective control by the participant than peripheral cue paradigms. Additional studies support both Jonides' general arguments about automaticity and the specific categories. For instance, it is clear that peripheral cues both capture and release attention very strongly and quickly, an effect that is resistant to suppression (Remington, Johnston, and Yantis, 1992; Muller and Rabbitt, 1989).

The overwhelming consensus from Jonides and other studies is that two separate mechanisms are involved for directing attention: one exogenous mechanism driven by peripheral cues, and one endogenous system driven by central cues (Cheal and Lyon, 1991; Nakayama and Mackeben, 1989). It is also fairly clear that separate neurophysiological substrates control each of these two systems. Central cues are processed by the geniculostriate, and ultimately parietal pathways, whereas peripheral cues, in line with their increased automaticity, are processed by the midbrain, superior collicular pathway (Rafal, Calabresi, Brennan, & Sciolto, 1989; Posner, Cohen, & Rafal, 1982; Robinson & Peterson, 1986).

If peripheral cues invoke a strategy that is inelastic to voluntary control, the structure of these attentional shifts will be entirely determined by the demands of the particular neurophysiology. Therefore, if indeed the hypothesized physiological inter-hemispheric transfer of information manifests itself as larger response times and decreased accuracy when crossing a vertical meridian, this effect will be more pronounced in this exogenous system.

Another issue that confronts general theories of attention is the task paradigm responsible for deriving them. All aforementioned support for a meridian effect in endogenous systems has come from studies that employed detection tasks (Hughes & Zimba, 1985; 1987; Tassinari, et al., 1987; Downing & Pinker, 1985; Rizzolatti, et al., 1987), a design that involves the detection of a light flash somewhere in the visual field. This design only measures whether or not subjects are aware that a stimulus is present—a very different thing from asking what stimulus is present (Shaw, 1984).

A more fruitful experimental paradigm is the discrimination task, where participants identify which of two possible targets is present in the visual field. Detection tasks involve a pre-attentive, early-processing strategy, but discrimination tasks involve an attentive, late-processing strategy (Sereno & Kosslyn, 1991; Egly & Homa, 1991). This difference in attention level for detection versus discrimination could be attributed to entirely different visual pathways, the midbrain versus geniculostriate pathways respectively, much like that described above in reference to the exogenous versus endogenous system (See also Spitzer, Desimone, and Moran, 1988, for neurophysiological studies of attention in cortical area V4). Because the present issue is the impact of crossing meridians on shifts of two kinds of attention, discrimination tasks are a more appropriate experimental choice. Due to these arguments, the authors of detection experiments in fact admit that their findings are limited to only very specific situations. Because we are here interested in exploring theories of attention in general and not within a particular paradigm, studies that utilize detection paradigms should be considered with caution.

Studies that employ the discrimination task in order to obviate the possibility that meridional effects are an artifact of detection experiments suggest that distance and not meridian boundaries is the largest hindrance in shifts of covert attention (Henderson & MacQuistan, 1993; Egly & Homa, 1991; Henderson, 1991).

Unfortunately, since the evolution of experimental paradigms from detection to discrimination, studies that examine effects of meridians have also focused exclusively on the exogenous system (Egly & Homa, 1991; Henderson, 1991; Henderson & MacQuistan, 1993). While these findings are useful, we are interested in these effects in both exogenous and endogenous systems.

As another note about methodology, the size of the display is an important concern both for looking at meridional effects and theories of attention in general. Disconfirmation of the analog spotlight metaphor and support for the gradient model (e.g., Downing & Pinker, 1985) involves movements as large

as 20 ° eccentricity. But these results are questionable because it makes sense that a beam size would enlarge in more peripheral locations where visual acuity is less rich than in foveal regions. Therefore, a more useful test of specific-location hypotheses and spotlight/zoom-lens models in particular is when the retinal eccentricity is fairly small.

The experimental design in the present study facilitates the best approach to these issues. Eight possible target locations equidistant from each other form an imaginary circle subtending 8° of visual angle with two locations in each quadrant. This design is particularly useful in regard to the relevant literature. For instance, Henderson (1991) introduced confounds into his design because targets were not equidistant; the distance between target locations across meridia was larger than that within quadrants, so it was difficult to tease apart increasing distance from the effect of crossing meridia. This design also allows for an analysis of same-quadrant measures without confounding meridia, a possibility left out of Egly & Homa's (1991) design. Further, this design permits an analysis of crossing meridia without changing direction, an important issue with regard to the hypotheses of Rizzolatti et al. (1987). Finally, the present study permits the analysis of crossing meridia without directly crossing the fovea, a suggested explanation for meridian effects (Downing & Pinker, 1985). Furthermore, this experiment uses a discrimination task along with both peripheral and central cues, allowing us to examine both attentional mechanisms in a single experiment.

The present study attempts to elucidate four issues:

First, does cue type impact the cost-benefit model as suggested by Jonides (1981) and others? While Jonides represented costs and benefits as a comparison to neutral cues, we are not including neutral cues in our experimental design. The expectation in this study, then, is to see large differences between response times to validly cued targets and response times to invalidly cued targets, a difference I will roughly refer to as the cost-benefit difference. This difference will be greatest for the peripheral cue blocks, because peripheral cues produce larger costs and benefits than central cues do. This will be reflected by the presence of fewer incorrect responses and faster response times for valid peripheral than valid central cues. Additionally, invalidly cued targets via peripheral cues will show more incorrect responses and slower response times than will invalidly cued targets via central cues. It is also possible that the cost-benefit differences for central cues will be indistinguishable from the cost-benefit differences in peripheral cues. Even in this situation, however, Hughes & Zimba's (1985; 1987) quadrant model is still disconfirmed a large cost-benefit difference is present in the central cue blocks. These authors did not include benefits of valid cues as part of their model; instead, it focused only on the inhibition created by a cue that invalidly cued targets must contend with. In other words, the quadrant model looks only at costs of entire regions—not benefits. But if response times to validly cued targets are faster than any invalidly cued targets—regardless of region—Hughes and Zimba's model must be wrong. Moreover, the relationship of these benefits to costs in the central cue tasks has strong implications for Tassinari et al.'s (1987) general region hypothesis, because they too included an incongruent cost-benefit model in their theory where validly cued targets were only responded to marginally faster than invalidly cued targets. Since this study does not employ a neutral cue it will be impossible to assess directly the magnitude of our costs separate from benefits. However, it is still possible to get a rough idea of the magnitude of the benefits by comparing validly cued targets to invalidly cued targets in other locations assuming, of course, that not all invalidly cued target locations are equal. This claim will also be addressed directly in additional predictions.

Second, are invalid cues within quadrants associated with costs? That is, does shifting attention to adjacent locations within a quadrant take more time than responding to validly cued targets? This is an important point because, if significant, it has immediate repercussions for both quadrant models (Hughes & Zimba, 1985; 1987; Tassinari, et al., 1987) where inhibition is diffuse over entire quadrants. If costs for shifting attention without crossing meridia are present, the quadrant model is disconfirmed. The expectation is for a pronounced distance effect in both cue conditions, where moving to a further distance within the same quadrant takes more time (Henderson & MacQuistan, 1993).

Third, does crossing meridia without moving extra distance take more time? In other words, are response times longer in cases where a meridian is crossed than when only a given distance is traversed? The expectation is for only a vertical meridian effect, if any, although previous studies have not shown effects of any meridia with peripheral cues (Egly & Homa; Henderson, 1991; Henderson & MacQuistan, 1993). In this case the cost-benefit difference between responding to a validly cued target and an invalidly cued target within the same quadrant will be less substantial than the difference when the invalidly cued target transcends the vertical meridian. If a vertical meridional effect is present for the peripheral cue blocks then this effect should also be present in central cues, though perhaps not as strongly. In other words, the

cost-benefit differences between same quadrant and different quadrants across the vertical meridian will be more pronounced in the peripheral cue condition than the central cue condition.

Fourth, is a distance effect present irrespective of cue type or meridia crossed? If this is the case, shifting attention to opposite quadrants (where the most distance is traversed) should be the most time-costly situation. Additionally, moving attention to diametrically opposite target locations should be more costly than moving to closer distances within this opposite quadrant, because this location is the furthest distance while still crossing both meridia. This effect should also hold for both cue types.

Methods

Participants

Twenty-five Colgate University undergraduates participated in a single one-hour experiment as partial completion of a requirement for an introductory psychology course. All participants reported having either normal or corrected-to-normal vision.

Apparatus and Stimuli

A Dell microcomputer with a CyberResearch CYCTM-05X timer/counter card provided millisecond timing and controlled stimulus presentation (via a standard 17" VGA monitor) and response acquisition (via a button box). Stimuli were displayed in a high-resolution graphics mode. Responses were made on a two-button response box with horizontally arranged buttons. All stimuli were yellow letters appearing on a black background. Targets were the letters S and Y, and distractors were the letters A, D, G, H, J, N, and P. Each letter subtended approximately 1.15° of visual angle in height and 0.72° in width from the viewing distance of 40 cm. Letters were presented on an imaginary circle centered at fixation, with two letters in each quadrant. The distance between the fixation point and the center of each letter was 4.00° ; the center-to-center distance between letters was 2.86° . The central cue was an arrowhead 1.00° long and 0.57° wide presented at fixation. The gap between the central cue and the letter that it indicated was approximately 2.86° . The peripheral cue was a flash 1.29° long and 0.29° wide presented 1.45° outside the target it indicated.

Procedure

Before commencing with the experiment, participants were instructed about the procedure both verbally and in writing. Participants were reminded to keep eyes fixated on the cross, to treat accuracy as the primary concern, and to do so while responding as quickly as possible. Two short practice blocks were initiated at the beginning of the experiment, after which participants could ask the experimenter any additional questions about the task.

A two-alternative forced choice task was used. Subjects were initially presented with an empty field. After 1500 ms a fixation cross appeared, followed 1000 ms later by either a central or peripheral cue of 70 % validity (seven out of ten cues directed participants to the correct target location, and three out of ten cues directed participants to an incorrect target location). After 150 ms an eight-letter string on an imaginary circle appeared for 50 ms. Participants then made a response about whether an S or Y was present in the display by pressing one of two buttons with left or right index fingers on a response board. Half the participants pressed a left button for S targets and right button for Y targets, and the other half did the reverse. The target location for S and Y was randomized throughout the experiment, as was the location of the invalid cues. If the participant made either an incorrect response, or no response within 3500 ms, the computer produced a 600-Hz, 100-ms tone followed by a 300-Hz, 100-ms tone. See figures 1a and 1b for an illustration of the procedure.

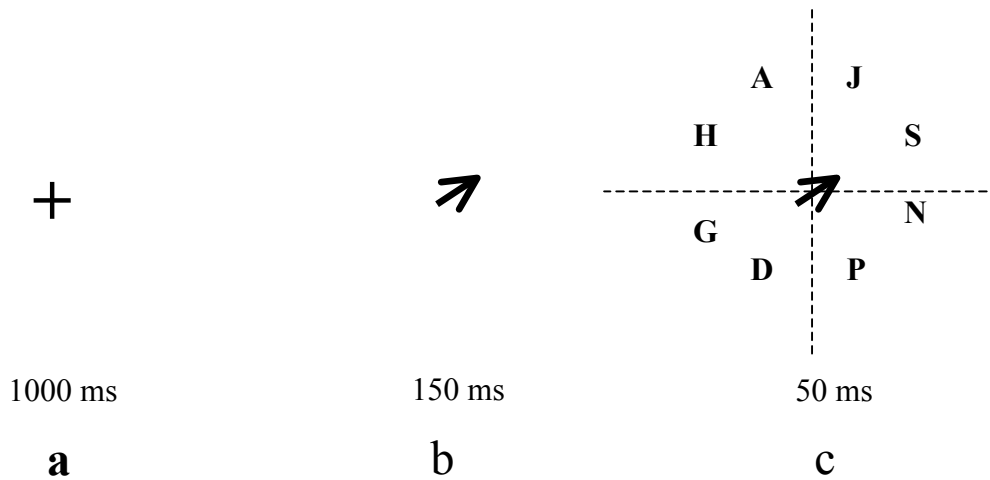


Figure 1a. Representation of the valid central cue condition, about half the actual size. a) Initial fixation point appears for 1000 ms; b) central cue appears for 150 ms in place of fixation; c) target circle appears for 50 ms. Dotted lines represent imaginary meridians of the visual display, lines not a part of the actual display.

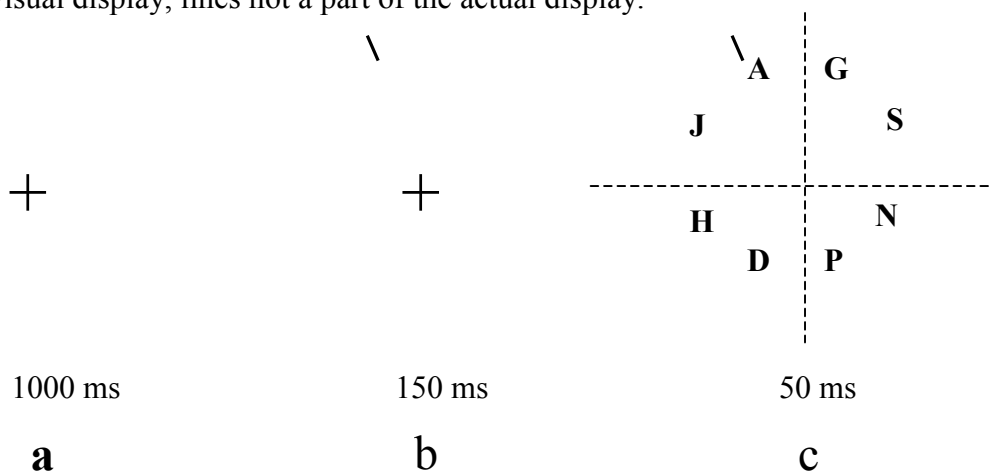


Figure 1b. Representation of the invalid peripheral cue condition, about half the actual display size. a) initial fixation point appears for 1000 ms; b) peripheral cue appears for 150 ms; c) target circle appears for 50 ms. Dotted lines represent imaginary meridians of the visual display, lines not a part of the actual display.

Participants repeated this procedure for ten blocks of 60 trials. Following each block a display appeared summarizing mean response times and overall accuracy. If participants' accuracy fell below 95 %, they were instructed by written form command from the computer to slow down in order to reduce errors. The cue type was held constant throughout an entire block, and block pattern was randomized. A short five to ten minute break was offered half-way through the experiment.

Results

A two-way within-subjects ANOVA was performed to compare cue type (central or peripheral) and cue validity (valid or invalid). Looking first at response times, no main effect of cue was found suggesting that the average response time following a cue was not significantly different for each cue type. However, there was a main effect for cue validity, $F(1, 24) = 128, p < .001$, demonstrating that participants were faster to respond to valid cues (579 ms) than invalid cues (786 ms). Additionally, an interaction was found between cue type and validity, $F(1, 24) = 30.6, p < .001$, demonstrating that participants responded more slowly to invalid peripheral cues (805 ms) than invalid central cues (766 ms), and more quickly to valid peripheral cues (556 ms) than valid central cues (602 ms). Table 1a lists the mean response times for each cue condition and validity. The error rates for cue types exactly mirrored the above response time patterns. A two-way within-subjects ANOVA was performed to examine the relationship between error rates and cue type. No main effect was significant for cue type, suggesting that the average rate of errors did not change depending on the type of cue. A main effect for validity was present, $F(1, 24) = 34.5, p < .001$, showing that participants made more errors when cues were invalid (14.7 %) than when cues were valid (3.4 %). Further, an interaction between cue type and error rates was present, $F(1, 24) = 18.8, p < .001$, representing the fact that participants made the most errors with invalid peripheral cues (16.3 %), substantial errors with invalid central cues (13.2 %), the fewest errors with valid peripheral cues (1.96 %), and few errors with valid central cues (4.78 %). Table 1b lists the mean error rates for each cue condition and validity. All of these findings strongly support previous comparisons of peripheral versus central cues (e.g., Jonides, 1981).

a)

| | <u>Central</u> | <u>Peripheral</u> |
|----------------------|----------------|-------------------|
| <u>Valid</u> | 602 ms | 555 ms |
| <u>Invalid</u> | 766 ms | 804 ms |
| <u>Invalid-valid</u> | 164 ms | 249 ms |

b)

| | <u>Central</u> | <u>Peripheral</u> |
|----------------------|----------------|-------------------|
| <u>Valid</u> | 4.78 % | 1.96 % |
| <u>Invalid</u> | 13.21 % | 16.29 % |
| <u>Invalid-valid</u> | 8.43 % | 14.33 % |

Table 1. Mean response times (a) and error rates (b) to validly or invalidly cued targets in both the central and peripheral cue conditions. Invalid-valid represents the cost-benefit difference. 1a lists response time results, 1b lists error rate results.

The influence of crossing meridians when making shifts of attention was first assessed with a two-way (2x3) within-subjects ANOVA comparing invalid cues (central or peripheral) that were directly adjacent to the target location (either within quadrants, across a vertical meridian, or across a horizontal meridian). The response time results show a main effect for cue type as expected, $F(1, 24) = 6.95, p = .001$. The mean response time for central cues (727 ms) was faster than the mean response time for peripheral cues (768 ms). A main effect for meridia was also present, $F(2, 48) = 6.27, p = .004$. This shows that it took more time to cross a horizontal meridian (772 ms) than to cross a vertical meridian (718 ms). No interaction was found for meridia and cue type. A Tukey's pairwise comparison was performed to contrast the response times for within quadrant, crossing a vertical, or crossing a horizontal meridian. No statistically significant difference was found between the relative costs for within-quadrant invalidly cued targets versus the relative costs of crossing a vertical or horizontal meridian. However, a statistically significant difference was present between crossing a horizontal versus vertical meridian. Thus, the meridional effect is constrained to a difference in costs between crossing a horizontal meridian to locate an invalidly cued target versus crossing a vertical meridian to respond to an invalidly cued target. The identical analyses for error rates do not mirror these meridional effects, however. No main effect was found for cue type ($F(1, 24) = 3.05, p > .05$) or meridian ($F(2, 48) < 1, p > .05$), nor was an interaction effect present ($F(2, 48) = 2.23, P > .05$). These results show that the effect of crossing meridians in shifts of

attention is most pronounced when comparing response times for the difference between horizontal and vertical meridians.

The overall distance effect was first analyzed without respect for meridians crossed, looking only at distance away from the cued location. A two-way (2x4) within-subjects ANOVA was performed comparing the cue type (central or peripheral) with distance (valid cue, adjacent, two locations away, three locations away, or diametrically opposite). See figure 2 for an illustration of this analysis.

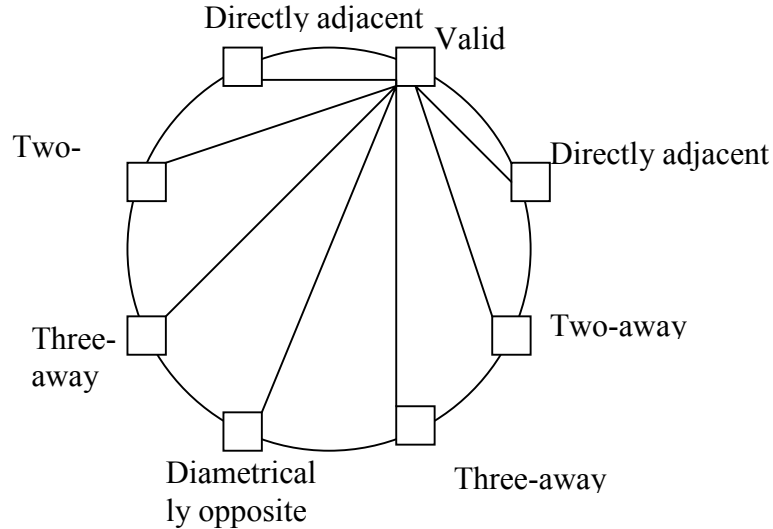


Figure 2. Schematic of the overall distance measure. Boxes represent target regions. Descriptors at each target location represent target location distance from the invalidly cued location. Response times and error rates were combined for targets appearing at identical distances from the cued location. Analyses were conducted for each cue type.

When looking at response times, a main effect for cue type was found, $F(1, 24) = 11.24, p = .003$. This shows that the average response time for central cues (730 ms) was faster than the average response time for peripheral cues (761 ms). A main effect for distance was also present, $F(4, 96) = 61.7, p = .000$, signifying that the average response time for valid cues (580 ms) was faster than the average response time for invalid cues to adjacent targets (751 ms), two locations away (808 ms), three locations away (809 ms) and diametrically opposite (780 ms). An interaction was also present between cue type and distance, $F(4, 96) = 12.5, p = .000$. This interaction represents the fact that the relationship between distance and invalid cues is different depending on the type of cue. See table 2a for mean response times at increasing distances from the cued location. A set of Tukey's pairwise comparisons were performed in order to measure where these distances were significant for each cue type. See table 3a for a listing of the significant findings of the pairwise comparison. In general, response times increased significantly with greater distance from the cued location. Note that the steady increase in response times decreases rather dramatically for the central cue location at the diametrically opposed position.

a)

| | <u>Average</u> | <u>Central</u> | <u>Peripheral</u> |
|----------------------|----------------|----------------|-------------------|
| <u>Valid</u> | 580 ms | 604 ms | 557 ms |
| <u>IV Adjacent</u> | 751 ms | 730 ms | 772 ms |
| <u>IV Two-away</u> | 808 ms | 794 ms | 823 ms |
| <u>IV Three-away</u> | 809 ms | 794 ms | 824 ms |
| <u>IV D.O.</u> | 780 ms | 730 ms | 829 ms |

b)

| | <u>Average</u> | <u>Central</u> | <u>Peripheral</u> |
|----------------------|----------------|----------------|-------------------|
| <u>Valid</u> | 3.43 % | 4.80 % | 2.07 % |
| <u>IV Adjacent</u> | 10.04 % | 8.04 % | 12.04 % |
| <u>IV Two-away</u> | 17.25 % | 15.28 % | 19.22 % |
| <u>IV Three-away</u> | 17.72 % | 17.23 % | 18.22 % |
| <u>IV D. O.</u> | 14.95 % | 13.75 % | 16.14 % |

Table 2. Mean response times (a) and error rates (b) for identifying targets located at increasing distances from the cued location (as shown in Figure 2). Average response times across cues are also shown.

These same analyses for error rates support the main effect for distance, $F(4, 96) = 20.44, p = .000$. The error rates for valid cues (3.43 %) were lower than the error rates for adjacent target locations (10.04 %), two away (17.25 %), three away (17.72 %), and diametrically opposite (14.95 %). In general, shifting attention further distances from the cued location results in a higher error rate. No other effects for error rates were found. See tables 2b and 3b for a listing of these findings.

a)

| | <u>Valid</u> | <u>Invalid Adjacent</u> | <u>Invalid Two-away</u> | <u>Invalid Three-away</u> | <u>Invalid D.O.</u> |
|----------------------|--------------|-------------------------|-------------------------|---------------------------|---------------------|
| <u>Valid</u> | ---- | Yes | Yes | Yes | Yes |
| <u>IV Adjacent</u> | ---- | ---- | Yes | Yes | No |
| <u>IV Two-away</u> | ---- | ---- | ---- | No | Yes |
| <u>IV Three-away</u> | ---- | ---- | ---- | ---- | Yes |
| <u>IV D.O.</u> | ---- | ---- | ---- | ---- | ---- |

b)

| | <u>Error Rates</u> | | | | |
|----------------------|--------------------|-------------------------|-------------------------|---------------------------|---------------------|
| | <u>Valid</u> | <u>Invalid Adjacent</u> | <u>Invalid Two-away</u> | <u>Invalid Three-away</u> | <u>Invalid D.O.</u> |
| <u>Valid</u> | ---- | Yes | Yes | Yes | Yes |
| <u>IV Adjacent</u> | ---- | ---- | Yes | Yes | Yes |
| <u>IV Two-away</u> | ---- | ---- | ---- | No | No |
| <u>IV Three-away</u> | ---- | ---- | ---- | ---- | No |
| <u>IV D. O.</u> | ---- | ---- | ---- | ---- | ---- |

Table 3. Above are shown the results of the Tukey's pairwise comparison for average response time (a) and error rates (b) as a function of distance. "Yes" represents a statistically significant difference, "No" represents a lack of statistically significant difference.

After seeing that overall distance is a significant factor in response times and error rates, I explored the impact of distance without crossing additional meridia. (See figure 3 for an illustration of this distance comparison.) A three-way (2x2x2) within-subjects ANOVA was performed comparing cue type (central or peripheral), distance (near or far), and crossing meridia (vertical or horizontal) in invalid cue conditions. When looking at response times, a main effect for cue type was present, $F(1, 24) = 6.59, p = .02$. Participants responded more quickly to central cues (752 ms) than peripheral cues (791 ms). A main effect was also present for meridia, $F(1, 24) = 17.73, p < .001$. Participants responded more quickly to targets across the vertical meridian from the invalid cue (744 ms) than across the horizontal meridian (798 ms). Additionally, a main effect was present for distance, $F(1, 24) = 14.0, p = .001$. Participants responded

more quickly to invalid cues that were separated by less distance from cued location (745 ms) than more distance (798 ms). No interactions were found. These results support the overall distance effect measured above, because moving further distances within a hemifield takes additional time.

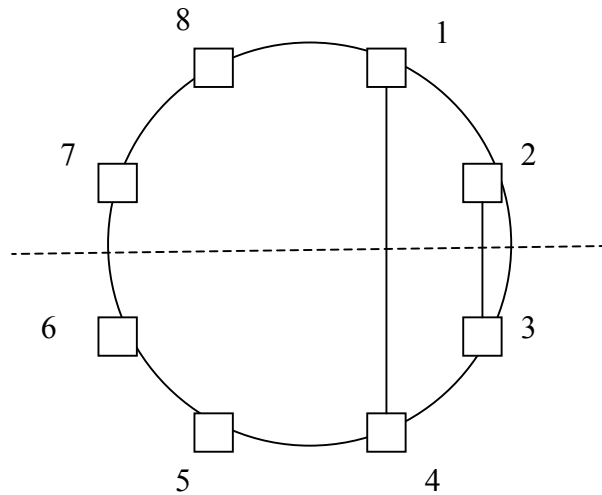


Figure 3. Schematic of the second distance comparison. Boxes represent target locations. The “near” condition is represented by an invalid cue to location “2” followed by a target at location “3.” The “far” condition is represented by an invalid cue to location “1” followed by a target at location “4.” Identical analyses were also conducted for near and far shifts of attention across the vertical meridian, and for each cue type.

The results of this analysis with respect to error rates does not entirely tell the same story. In this case, no main effect for cue type or meridian was present, but a main effect was present for distance, $F(1, 24) = 10.42$, $p = .004$, where shorter shifts of attention produced smaller error rates (10.97 %) than longer shifts of attention (16.87 %). Additionally, no interaction was found for cue type with meridia, cue type with distance, meridia with distance, or all three factors ($F(1, 24) = 4.03$, $p > .05$).

Discussion

The results of this experiment support some of my specific hypotheses, but are somewhat ambiguous with regard to supporting a particular theory of attention for each or both attentional mechanisms. We can explore the overall effects of cue type, distance, and meridia, while placing particular focus on how these results do or do not fit into specific theories.

First, the strong effect of cue type for the characteristics of this cost-benefit relationship lends further support to the already plentiful body of evidence for the separation between endogenous and exogenous attentional systems (e. g., Remington, Johnston, & Yantis, 1992; Muller & Rabbitt, 1989; Cheal & Lyon, 1991; Nakayama & Mackeben, 1989). Valid peripheral cues facilitated quicker responses to targets with higher accuracy than valid central cues. Likewise, peripheral cues also appeared more resistant to suppression than central cues, as evidenced by the greater costs and poorer accuracy in conditions when they invalidly directed attention. These data justify the acceptance of the related claims of previous studies for characteristics of these attentional mechanisms.

Generally speaking, the overall existence of a cost-benefit effect of cues is an encouraging baseline for further analysis, one Hughes & Zimba (1985; 1987) and Tassinari et al. (1987) failed to adequately produce. First, in both cue conditions I found robust benefits of valid cues that were mirrored by congruent costs. Recall that the benefits in these aforementioned studies either found no benefits of valid cues (Hughes & Zimba, 1985) or ‘mild’ benefits which are incongruent with overall costs (Hughes &

Zimba, 1987; Tassinari, et al., 1987). My data for both cue types fit into the cost-benefit paradigm in a way that these studies do not.

If the failure to accommodate the cost-benefit paradigm is not concern enough for the general region hypotheses, additional disconfirmational evidence is provided by the response times for locations within the same quadrant as the cued location. The quadrant hypothesis argues that attention is diffusely distributed throughout a hemifield (Hughes & Zimba, 1985) or quadrant (Hughes & Zimba, 1987; Tassinari, 1987) and therefore costs are equivalent throughout the area. In the present experiment, however, both cue conditions showed marked costs for both response times and error rates within the same quadrant as the invalidly cued location. This immediately contradicts Hughes & Zimba's (1985) results, where no differences were found between validly cued targets and invalidly cued targets within the same hemifield. However, since I could only compare two locations within a quadrant, I cannot comment on Hughes & Zimba (1987) or Tassinari et al.'s (1987) results where different invalidly cued targets within a region did not show different costs.

However, a directly related claim of the latter two studies is a markedly strong cost for accurately responding to targets directly adjacent to the cued location. These authors termed this the inhibitory after-effect, as represented by a small ring of inhibition surrounding the cued location. The very presence of such a dip in an otherwise diffuse distribution of attentional resources is a conceptual conundrum, and might be attributable to the detection experiments used in these studies. The peripheral flashes used in detection experiments could quite conceivably inhibit immediate attention at that location, where it is an inhibition of detection and not inhibition or reorientation of attention. If the inhibitory after-effect is indeed an artifact of the detection experiments, the expectation is to not find them in discrimination experiments. Indeed, the present experiment shows no such effect. Locations directly adjacent to the cued location showed marked costs, but costs that were not any greater than those of other invalidly cued target locations. Judging from these findings alone, the general region hypothesis cannot conceivably account for my data in either cue condition. Instead, these findings lend support for a specific-location hypothesis.

Additionally, a strong distance effect is present for both cue types, irrespective of crossing meridians. Generally speaking, moving attention to locations further distances resulted in greater costs in a roughly linear way. This pattern is most pronounced for peripheral cues. As distance from cued location increased, response times and error rates also increased, with diametrically opposite positions the most costly. This finding supports previous findings (Henderson, 1991; Henderson & MacQuistan, 1993; Egly & Homa, 1991) and is explained by both spotlight, zoom-lens, and gradient models.

This overall distance effect was similar in the central cue, although the linear effect is not as pronounced. This could make sense because, as noted in the introduction, the peripheral cues are automatic and less malleable to subjective control. Central cues, on the other hand, are more endogenously controlled. It is possible that the distance effect in central cue paradigms is compromised by another effect, perhaps regional location. The fact that the diametrically opposite position was less costly in invalid conditions could be because subjects were able to 'see' the display in a locationally representative way, so targets directly opposite the location in question were responded to with less difficulty.

Some support for facilitation of targets in the diametrically opposite position exists (Eriksen & Collins, 1969; Skelton & Eriksen, 1976). Eriksen and Colegate (1970) showed that targets in locations adjacent to endogenously cued locations produce lesser costs than than targets at diametrically opposite locations, but the diametrically opposite location is still better than other regions. The proposal is that more than a single location is attended to at a given time, albeit less strongly. Eriksen & Yeh (1985) deny this possibility of attending to two locations simultaneously. In this study, peripheral cues of varying reliability were used, with a second position also possible. Cues were 40 %, 70 %, and 100 % valid, with secondary positions 40 %, 10 %, or 0 % valid, respectively. The results of this study were that even when the secondary position was equally valid, participants still reacted to the cued target location the fastest. In fact, the time to attend to the diametrically opposite position was nearly identical to the uncued situations. However, only peripheral cues were used in this study. Jonides' (1981) and other studies suggests that peripheral cues are very resistant to expectancy of participants. This suggests that we would not expect a large difference depending on validity, an expectation consistent with Eriksen & Yeh's findings. Additionally, because peripheral cues are also resistant to suppression, we would expect that no matter what the expectancy, peripheral cues to a particular location would draw participants attention there automatically. Again, Eriksen and Yeh's findings are consistent with this expectation. These arguments are also consistent with my findings, where diametrically opposed targets in peripheral cue situations took no less time to attend to invalidly cued locations than other distances.

However, it is not clear that we should expect Eriksen & Yeh's (1985) results from central cues, conditions that are apparently somewhat sensitive to expectancy and also less resistant to suppression. In the present study, the facilitation of positions diametrically opposed to the target location is significant when compared to other invalid cues. In fact, it took almost as much time to identify targets diametrically opposite to the cued location as it did to identify targets directly adjacent to cued location. However, the presence of the finding does suggest that perhaps participants are engaging in a moderate split of their attentional resources, a possibility suggested by Eriksen & Collins (1969). The point is not that the diametrically opposite position is attended to equal to the cued location; rather, some attentional resources are focused on this location because of its representational location in visual space. The tendency in the literature is to dichotomize serial versus parallel processing with shifts of attention (Jonides, 1983), a distinction largely dependent on task difficulty (Eriksen & St. James, 1986). It seems possible, however, that in our moderately difficult task participants could be employing a mostly serial processing strategy with marginal utilization of some parallel strategies. This sounds much like the continuum suggested by Eriksen & Yeh (1985) where serial and parallel strategies fall on opposite endpoints. Further support for this claim comes from Johnson & Yantis (1995) who reject Jonides' two-process model of attention in conditions when cues are partially valid, a condition clearly present in my experiment where cues were 70 % valid.

It was impossible to directly measure this effect due to insufficient data in the present study, but further experiments could follow up on this hypothesis in a few ways. First, I could restrict the task to more blocks of central cues alone, thereby increasing the number of trials where the diametrically opposite position is the target location. I could statistically measure whether invalid cues with targets at this location produce lesser costs than the adjacent location in this quadrant. Further comparisons of diagonally opposite locations with targets skewed from this diagonal could measure whether or not this representational aspect has any support.

These claims are conjectural at best, but if they are legitimate they immediately question the possibility that general attentional models are equally applicable to both the exogenous and endogenous system. Additionally, they somewhat question the parsimony of a purely specific-location model of attention particularly in the endogenous system. It is likely that participants utilize a combination of different attentional strategies when presented with central cues, not one or the other. We will return to this possibility after examining the meridional findings.

The meridian results are somewhat puzzling. First of all, the meridian effect that was expected due to neurophysiological evidence—the vertical meridian—is not as pronounced as expected. This could make sense if taken alone, but the strong effect of crossing the horizontal is somewhat peculiar. The only meridional effects present were with response times—no differences were found with error rates. The response time differences were also not pronounced when comparing the costs for crossing one meridian with no meridian, but the difference between crossing a vertical or horizontal was significant. No significant interaction effect for cue type with meridia, so we cannot appeal to a difference between attentional mechanisms as an explanation.

These findings, while unexpected, are not entirely unsupported by the literature. Henderson & MacQuistan (1993) report marginal costs for moving across the vertical meridian in their first two experiments. However, they attempt to explain away this marginal finding in their third experiment by removing the very high error rates they found in their first two experiments (roughly 62 %). Reducing these exceedingly high error rates is clearly a legitimate concern, but their implementation of this goal is questionable. They left target fields on the display until a response was made, a procedure that produced the expected near 100 % accuracy, and as a result no meridian effects were found in the response times. The efficacy of this methodology is lacking because it seems clear that participants are free to foveate on the targets with saccades, thereby ignoring the issue at hand: the role of moving covert attention across meridia. As a result of these findings, the authors suppose that their meridional findings are artifactual, and provide no additional explanations for why they might occur.

Rizzolatti, et al. (1987) explain their meridional effects as attentional pre-programming connected to the overt eye-movement system. In covert attentional movements, these authors argue, the same visual pathways are involved as in overt movements, except that the movement never takes place. In other words, covert movements of attention are roughly the planning program of an overt eye movement. Rizzolatti and authors use this as an explanation for the meridian effects because a new “direction” component needs to be re-programmed into the attentional mechanisms. This hypothesis has a few problems. First of all, it is rather accepted fact that the two forms of covert attention do not work on the same visual pathway as overt eye

movements. In fact, while the exogenous system is associated with the eye movement mechanisms, the endogenous system is not (Rafal et al., 1989; Posner, Cohen, & Rafal, 1982; Robinson & Peterson, 1986). Further, this explanation can only account for meridian effects when the target is in the opposite direction from the cued location. In the present study, however, significant effects were found for crossing meridians in both cue types even when no changes in direction had to take place.

Downing & Pinker (1985) suggest a gradient model of attention as an explanation for meridian effects. This is neither a pre-movement system, nor does it appeal to the transfer of information between hemispheres, a potential explanation suggested in the introduction to this paper. It is partly an issue of crossing the foveal regions of the retina. Foveal regions are more densely populated with neuronal connections, and are therefore more represented by cortical space. This initial component of Downing & Pinker's explanation does not fit with my data, however. These authors used a very large display, approximately 22.50° in diameter. They argue that the representational gradient is influenced by a change in receptive field size that is directly tied to cortical mapping. In the present study the display only subtends 8° of visual angle. Therefore, the pronounced meridian findings in the present study could not possibly be from moving across the fovea. Furthermore, meridional effects were not only present when crossing the foveal region. In fact, the pronounced meridian effects are when shifting attention from one point on the circumference of the imaginary circle to another, without any change in retinal eccentricity.

Another compelling component of Downing & Pinker's gradient theory of attention is what they call the visual-angle scale of mental representation. This is presumably both a vertical and a horizontal regional aspect of space. This suggestion is supported by Sereno & Kosslyn (1991) who argue that appealing to a lateralization of the visual system as a sole explanation for meridional effects (vertical only) might be neglectful of other neurophysiological evidence. For instance, areas of extrastriate cortex appear to map visual space with respect to horizontal meridians (Van Essen, 1985). Indeed, the brain may organize information according to locational aspects more elaborately than many authors have considered.

This suggestion is reminiscent of the proposal in the present study that in endogenous systems participants are able to apply a mental representation to the display. This might explain both the meridional findings as well as the lesser costs at diametrically opposite positions. If we are willing to accept a vertical/horizontal representation of space with endogenous attentional mechanisms, we might also consider the possibility of a diagonal representation, one on which diametrically opposite locations are quickly compared.

However, if we choose to accept Downing & Pinker's explanation for meridional effects, we must be wary of three different aspects of their experimental paradigm: 1) detection tasks of luminous flashes; 2) endogenous cues centered at fixation; and, perhaps most importantly, 3) three-dimensional space. Therefore, if we can accept anything from this experiment we must be willing to accept that it is not necessarily applicable to the discrimination paradigm, the exogenous system, or two-dimensional visual space.

We are thus bereft of a comprehensive explanation for all of our findings from the existing literature. Excepting the meridional component, the peripheral cue patterns are well accounted for by either a zoom-lens or a gradient model of attention. Henderson (1991) questions the efficacy of a zoom-lens model to account for movements of attention taking longer with increasing distance. He says that the size of the lens does not account for distance as a functional parameter, and instead includes a small gradient around the edge. His argument is based on the fact that in his study more time was required to reorient attention in larger cued locations than smaller, but the larger zoom-lens should take less time. Although a zoom-lens model equipped with a time-to-move component could account for this effect, Henderson argues that a gradient model is the most parsimonious account for shifts of exogenous attention. Because only one cue and target size was used throughout my study, there is no way to determine whether Henderson's objections to the zoom-lens model are applicable to our data for peripheral cues.

Egly & Homa (1991) reject a gradient model as an explanation for their substantial distance effects with peripheral cues, and instead support a zoom-lens model. However, these authors did not find significant meridian effects, but do report substantial inhibitory after-effects in their data. It is this part of Egly & Homa's results that motivate the authors to reject a gradient model, because they cannot imagine what that sort of dip in the gradient would look like. Egly & Homa's objections are not compelling, though, in light of the fact that my study reports no such findings, and do have significant meridian effects.

It is certainly clear that a pure general region model is not appropriate for shifts of covert attention facilitated by either central or peripheral cues. The movements of attention reported in the peripheral cue condition are equally accounted for by a gradient, zoom-lens, or spotlight model, but only the gradient

model adequately accounts for the horizontal meridian effect. Furthermore, only the gradient model can account for the partial facilitation of targets diametrically opposite the central cue. Because my study was primarily an attempt to include many different aspects of shifting covert attention in visual space, it was impossible to explore the nuances of individual theories. Further experiments are necessary to tease apart the specific implications of each theory.

Acknowledgements

I first thank the Barge for providing me with an office throughout the course of this project. I also thank professors Richard Braaten and Scott Kraly for providing feedback and commentary on this paper. I am indebted to Doug Johnson for his seemingly limitless commitment of time, energy, and support, at literally any hour of the day, day in the week, or week in the year. Most importantly, I thank Scott Kraly, Doug Johnson, and the Neuroscience program for allowing me the leeway to design and implement this project with more emphasis on my own interests and curiosity than for traditional stipulations of the degree.

References

- Cheal, M. L., & Lyon, R. D. (1991). Central and peripheral precuing of forced-choice discrimination. Quarterly Journal of Experimental Psychology, *43A*, 859-880.
- Downing, C. J., & Pinker, S. (1985). The spatial structure of visual attention. In M. I. Posner & O. S. M. Marin (Eds.), Attention and performance XI (pp. 171-188). Hillsdale, NJ: Erlbaum.
- Downing, C. J. (1988). Expectancy and visuo-spatial attention: Effects on perceptual quality. Journal of Experimental Psychology: Human Perception and Performance, *14*, 188-202.
- Egly, R., & Homa, D. (1991). Reallocation of visual attention. Journal of Experimental Psychology, *17* (1), 142-159.
- Eriksen, C. W., & Collins, J. F. (1969). Temporal course of selective attention. Journal of Experimental Psychology, *80*, 254-261.
- Eriksen, C. W. & Colegate, R. L. (1970). Selective attention and serial processing in briefly presented visual displays. Perception and Psychophysics, *11*, 169-171.
- Eriksen, C. W., & Yeh, Y. (1985). Allocation of attention in the visual field. Journal of Experimental Psychology: Human Perception and Performance, *11*, 583-597.
- Eriksen, C. W., & St. James, J. D. (1986). Visual attention within and around the field of focal attention: A zoom-lens model. Perception and Psychophysics, *40*, 225-240.
- Gazzaniga, M. S. (1985). The Social Brain: Discovering the Networks of the Mind. New York: Basic Books.
- Gazzaniga, M. S. (1995). Principles of human brain organization derived from split-brain studies, Neuron, *14*, 217-228.
- Helmholtz, H. von (1866). In Treatise on Physiological Optics, (3rd edn., Vol. III, J. P. C. Southall, Ed. & Trans.). Washington, DC: The Optical Society of America. 1925.
- Hughes, H. C., & Zimba, L. D. (1985). Spatial maps of directed visual attention. Journal of Experimental Psychology: Human Perception and Performance, *11* (4), 409-430.

- Hughes, H. C., & Zimba, L. D. (1987). Natural boundaries for the spatial spread of directed visual attention. Neuropsychologia, *25* (1A), 5-18.
- James, W. (1890). The Principles of Psychology. Cambridge, MA: Harvard University Press.
- Johnson, D. N., & Yantis, S. (1995). Allocating visual attention: Tests of a two-process model. Journal of Experimental Psychology: Human Perception and Performance, *21* (6), 1376-1390.
- Jonides, J. (1981). Towards a model of the mind's eye's movement. Canadian Journal of Psychology, *34* (2), 103-112.
- Jonides, J. (1983). Further toward a model of the mind's eye's movement. Bulletin of the Psychonomic Society, *21* (4), 247-250.
- Kinsbourne, M. (1987). Mechanisms of unilateral neglect. In M. Jeannerod (Ed.), Neurophysiological and neuropsychological aspects of spatial neglect. New York: North Holland.
- Klein, R., & McCormick, P. A. (1989). Covert visual orienting: Hemifield-activation can be mimicked by zoom lens and midlocation placement strategies. Acta Psychologica, *70*, 235-250.
- LaBerge, D. (1983). Spatial extent of attention to letters in words. Journal of Experimental psychology: Human Perception and Performance, *9*, 371-379.
- McCormick, P. A., & Klein, R. (1990). The spatial distribution of attention during covert visual orienting. Acta Psychologica, *75*, 225-242.
- Muller, H. J., & Rabbitt, P. M. A. (1989). Reflexive and voluntary orienting of visual attention: Time course of activation and resistance to interruption. Journal of Experimental Psychology: Human Perception and Performance, *15*, 315-330.
- Nakayama, K., & Mackeben, M. (1989). Sustained and transient components of focal visual attention. Vision Research, *29*, 1631-1647.
- Pashler, H. (1998). Attention. San Diego: Psychology Press.
- Petersen, S. E., Robinson, D. L., Morris, J. D. (1987). Contributions of the pulvinar to visual spatial attention. Neuropsychology, *25*, 97-105.
- Posner, M. I., Cohen, Y., & Rafal, R. D. (1982). Neural systems control of spatial orienting. Philosophical Transactions of the Royal Society of London, *B298*, 187-198.
- Posner, M. I., Walker, J. A., Friedrich, F. J., & Rafal, R. D. (1984). Effects of parietal lobe injury on covert orienting of visual attention. Journal of Neuroscience, *4*, 1863-1874.
- Posner, M. I. & Petersen (1990). The attention system of the human brain. Annual Review of Neuroscience, *13*, 25-42.
- Rafal, R. D., Calabresi, P. A., Brennan, C. W., & Sciolto, T. K. (1989). Saccade preparation inhibits reorienting to recently attended locations. Journal of Experimental Psychology: Human Perception and Performance, *15* (4), 673-685.
- Remington, R., & Pierce, L. (1984). Moving attention: Evidence for time-invariant shifts of visual selective attention. Perception & Psychophysics, *35* (4), 393-399.
- Remington, R., Johnston, J. C., & Yantis, S. (1992). Involuntary attentional capture by abrupt onsets. Perception and Psychophysics, *35*, 393-399.

Reuter-Lorenz, P. A., Kinsbourne, M., & Moscovitch, M. (1990). Hemispheric control of spatial attention. Brain and Cognition, *12*, 240-266.

Rizzolatti, G., Riggio, L., Dascola, I., & Umiltà, C. (1987). Reorienting attention across the horizontal and vertical meridians: Evidence in favor of a premotor theory of attention. Neuropsychologia, *25*, 31-40.

Robinson, D. L., & Petersen, S. E. (1986). The neurobiology of attention. In W. Hirst & J. Ledoux (Eds.), Mind and brain. Cambridge: Cambridge Univ. press.

Shaw, M. L. (1984). Division of attention among spatial locations: A fundamental difference between detection of letters and detection of luminance increments. In H. Bouma & D. G. Bonwhuis (Eds.), Attention and performance X (pp. 109-120). Hove, UK: Lawrence Erlbaum Associates Ltd.

Shulman, G. L., Remington, R., & McLean, J. P. (1979). Moving attention through visual space. Journal of Experimental Psychology: Human Perception and Performance, *5*, 522-526.

Tassinari, G., Aglioti, S., Chelazzi, L., Marzi, C. A., & Berlucchi, G. (1987). Distribution in the visual field of the costs of voluntarily allocated attention and of the inhibitory after-effects of covert orienting. Neuropsychologia, *25* (1A), 55-71.

Tsal, Y. (1983). Movements of attention across the visual field. Journal of Experimental Psychology: Human Perception and Performance, *9* (4), 523-530.

Van Essen, D. (1985). Functional organization of primate visual cortex. In A. Peters & E. G. Jones (Eds.), Cerebral Cortex, Vol. 3 (pp. 259-329). New York: John Wiley and Sons.