Oculomotor readiness and covert orienting: Differences between central and peripheral precues

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The costs produced by invalid precues can depend on the spatial relationship between the cued location and the target location. If oculomotor programs mediate attention shifts, then the effect of varying the spatial relation between the cue and target should be the same for covert orienting (indexed by manual responses) and saccadic responses. We found this to be true only for central precues. With central precues, both manual and saccadic costs were greater when cue and target occurred on opposite sides of the vertical meridian than when they occurred on the same side. With peripheral precues, there were no meridian effects in either response condition, but there was a significant dissociation in the pattern of saccadic and manual costs. For manual responses costs were greater when the target was eccentric relative to the cue, whereas for saccades costs were greater when the cue was eccentric to the target. These results provide additional support for the idea that different orienting mechanisms are engaged by central and peripheral precues. They further suggest that the relationship between oculomotor and attentional orienting may depend on the nature of the precue, with the potential for interdependence being greater with central precues.

Normally, our attention and gaze move together. However, it is possible to pay attention to one location while maintaining fixation at another. This ability has been demonstrated experimentally by cuing a spatial location prior to the onset of a target (Eriksen & Hoffman, 1972; Posner, 1980). Even in the absence of overt eye movements, observers respond faster and more accurately when the target appears at a cued location than when it appears elsewhere (Hawkins et al., 1990; Müller & Humphreys, 1991; Posner, 1980). Some investigators have characterized covert attention as a beam or spotlight that can be moved through space (Posner, Snyder, & Davidson, 1980; Remington & Pierce, 1984), while others have suggested that it can be described as a zoom lens that goes from a broad to a narrow focus (Eriksen & Yeh, 1985; Murphy & Eriksen, 1987). Both hypotheses entail the notion that attention is oriented or directed to a circumscribed region

of space. The mechanisms underlying this ability are not well understood.

It has been proposed that movements of attention may be accomplished via the same motor programs that are used to make saccadic eye movements (see Klein, 1980). According to this hypothesis, attending to a location consists of generating an oculomotor program to move the eyes to that location. In the case of covert attention shifts, the saccade is not executed. Although this view has intuitive appeal, initial tests provided no support for it (Klein, 1980; Posner, 1980).

Nevertheless, interest in this premotor hypothesis has recently been revived by Rizzolatti and his colleagues (Rizzolatti, Riggio, Dascola, & Umiltà, 1987; see also Tassinari, Aglioti, Chelazzi, Marzi, & Berlucchi, 1987). In a luminance-detection task with spatial precues, they found that invalid cues produced longer simple manual response latencies (i.e., costs were greater) when the cue and target were on opposite sides of the vertical or horizontal meridians than when the cue and target were on the same side. Although the need for interhemispheric interactions could explain the extra costs across the vertical meridian, this explanation cannot account for the costs associated with the horizontal meridian (e.g., Hughes & Zimba, 1985, 1987). Furthermore, since the arrays of possible target locations used by Rizzolatti et al. were never centered on the fovea, the extra costs as-

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sociated with meridian crossings cannot be explained by the need for the attentional focus to traverse the large cortical region representing the fovea (e.g., Downing & Pinker, 1985).

As an alternative, Rizzolatti et al. (1987) interpreted the meridian effects in terms of saccadic programming. They reasoned that if a saccadic program is generated in response to a cue, invalid trials would require a modification of that program. Direction changes are required when the cue and target fall on opposite sides of the horizontal or vertical meridian, whereas only amplitude changes are required when the cue and target occur in different locations on the same side of the meridians. Evidence suggests that computations associated with saccade direction may take more time than the computations associated with programming amplitude (e.g., Becker & Jergens, 1979; Komoda, Festinger, Phillips, Duckman, & Young, 1973; however, see Abrams & Jonides, 1988). Therefore, Rizzolatti et al. proposed that the extra attentional costs associated with meridian crossings reflected the greater time required to change the direction parameter of the oculomotor program.

In a simple reaction time (RT) task, the same response is required regardless of the target position. Subjects are, therefore, likely to prepare the same manual response program irrespective of the cued location. However, the hypothesis proposed by Rizzolatti et al. (1987) makes an intriguing claim: If covert orienting depends upon oculomotor programs, then the latency of the nondirectional (simple manual) response reflects the time required to reprogram a directional (saccadic) response. A comparison of the effects of spatial precues on saccadic latencies and simple manual RTs is required in order to evaluate this claim. If precuing effects reflect the time course of saccadic reprogramming, then the pattern of costs for covert orienting indexed by manual response latencies should correspond closely to the pattern obtained with saccadic responses. For example, if meridian effects found with covert orienting reflect the relative rates at which saccadic amplitude and direction can be modified, similar meridian effects should also be obtained when subjects actually make saccadic responses.

To evaluate these predictions, two experiments were performed that compared the effects of spatial precues on simple manual responses and saccadic eye movements in the same subjects. Since central and peripheral precues may involve different attentional mechanisms (Briand & Klein, 1987; Jonides, 1981; Shepherd & Müller, 1989), the first experiment used peripheral precues and the second used central cues.

EXPERIMENT 1

Method

Apparatus. An IBM PC AT microcomputer with a Kinetic Vision Systems vector generator produced and controlled the stimulus displays. Data Translation DT2821 A/D converters were used to record response latencies. The stimuli were presented on a Hewlett-Packard 1310A large screen x-y monitor with a fast phos-

phor (P15). Display refresh and response sampling were synchronous at 250 Hz. Eye movements were monitored with a Purkinje-image eye tracker. Head motion was minimized with a bite-bar/headrest assembly.

Displays. Four outline boxes ($.66^\circ \times .66^\circ$) defined the target locations. These boxes were horizontally aligned on an oscilloscope screen, 2° and 6° to the left and right of a central fixation point. The precue consisted of a second outline box ($1^\circ \times 1^\circ$) briefly flashed around one of the target locations. The target was a $.5^\circ \times .5^\circ$ X presented within one of these boxes.

Procedure. At the start of each trial, the array of four boxes and the central fixation point appeared on the CRT screen. When the subjects were fixating the central point, the cue appeared for 300 msec. The target was presented after a randomly selected inter-stimulus interval of 500 to 800 msec, providing that the subject's gaze remained within $.25^\circ$ of the fixation point. If this criterion was not met, the target presentation was delayed until it was met or until 1,200 msec had elapsed since onset of the cue. Trials in which this maximum stimulus onset asynchrony (SOA) was exceeded were aborted and subsequently rerun. The range of SOAs used was similar to the range used in previous investigations of meridian effects (Hughes & Zimba, 1985, 1987; Rizzolatti et al., 1987). After the target appeared, it remained on the screen until the subject responded or until 2 sec had elapsed. In different trial blocks, the subject responded to the target onset either by pressing a response button with his/her right hand or by making a saccade to the target location.

At the start of each experimental session, a fixation matrix was used to calibrate the eye tracker so that 1 analog-to-digital conversion increment equaled 1 min of arc. Small drifts in baseline eye position were corrected in the course of each session while the subject fixated the central point. Saccadic responses were detected with a position criterion. The onset of a saccade was taken to be the time at which the eye moved more than $.5^\circ$ in the direction of the target, if the eye continued to move at least three fourths of the distance to the target position. Rare trials in which this criterion was not met, or in which an initial saccade was made in the wrong direction, were aborted and subsequently rerun.

Seventy-five percent of the trials were valid, with the target appearing in the cued location. The remaining 25% were invalid, with the cue and target appearing in different locations. All possible invalid cue-target pairings were presented with an equal probability. For each response type, 768 trials were run, of which 192 were invalid. The subjects participated in eight experimental sessions, approximately 60 min long, over the course of 2-4 weeks. During each session, two blocks of 48 trials were run for each response type in a counterbalanced order. Upon the completion of a subset of 192 trials in each response condition, a preliminary analysis was performed to identify and eliminate outliers. At that time, trials with latencies falling more than two standard deviations above or below the mean for that subset were rerun along with any previously aborted trials. Records of rejected trials were subsequently analyzed to evaluate the occurrence of anticipations and errors.

Subjects. Five student volunteers with normal or corrected-to-normal vision were paid for their participation.

Results

Latency analyses. The group means obtained with valid and invalid cues for each response condition are presented in Table 1. The spatial position of the cue and target are indicated by a two-digit code in which the first digit refers to cue position and the second digit indicates target position. Going from left to right in Figure 1, the numbers correspond to each of the four location boxes, with the far left position designated as 1 and the far right position designated as 4.

Table 1
Average Latency (in Milliseconds), for Manual and Saccadic Responses for all Cue-Target Pairs

Cue-Target Pair	Experiment 1 Peripheral Cue		Experiment 2 Central Cue	
	Manual	Saccadic	Manual	Saccadic
1:1	280	292	270	263
2:1	339	322	304	284
3:1	334	321	327	320
4:1	343	328	326	325
2:2	272	294	264	278
1:2	301	340	293	307
3:2	311	324	310	320
4:2	294	330	324	324
3:3	274	282	265	281
1:3	305	331	312	335
2:3	312	319	309	315
4:3	300	343	283	301
4:4	285	283	275	272
1:4	335	338	331	337
2:4	330	331	330	333
3:4	312	312	286	300

Target Locations

Figure 1. Diagram of stimulus display used in Experiments 1 and 2. Numbers in boxes are the numeric designations used in the tables and the text and did not actually appear in the experiments.

We computed "costs" by subtracting the mean latency of valid trials from the mean of invalid trials for each target position. Although this difference includes both the benefits of valid cues and the costs of invalid cues relative to a neutral baseline, we cannot separately evaluate these components in the absence of a neutral condition. We refer to the valid-invalid difference as "costs" for the sake of brevity.

The mean latencies in Table 2 indicate that both saccadic and manual responses were faster on valid than on invalid trials. An analysis of variance (ANOVA) confirmed the significance of cue validity [$F(1,4) = 111.3$, $p < .001$]. However, no difference was found between the manual and saccadic response conditions. Costs were, in fact, identical at 40 msec for both conditions.

The effect of the spatial relationship between the cue and target was initially evaluated for each response condition by comparing the costs for the following four cue-target pairs: (1) those separated by 4° and falling in the same hemifield, (2) those separated by 4° and falling on opposite sides of the vertical meridian, (3) those separated by 8° and falling on opposite sides of the vertical meridian, and (4) those separated by 12° and falling on opposite sides of the vertical meridian. In a two-way

ANOVA with response condition and cue-target pair as factors, only the effect of cue-target pair was reliable [$F(3,12) = 4.67$, $p < .02$], indicating that regardless of response condition, costs were reliably influenced by the spatial relation of the cue and target. The comparison between the 4° same and opposite pairs is critical to evaluating the meridian effect, since the retinal separation between cue and target is the same for these pairs. However, a Newman-Keuls analysis indicated that this comparison was not significant. The 12° cue-target pair differed significantly from the three other pairs ($p < .05$), and these were the only significant differences. The relevant costs are shown in Table 3.

Further analyses, however, revealed that the relative eccentricity of the cue and target produced markedly different effects for the manual and saccadic conditions. This is evident when costs associated with pairs in which the cued location is eccentric to the target (1:2, 1:3, 4:2, 4:3) are compared with costs from pairs in which the target is eccentric to the cued location (2:1, 2:4, 3:1, 3:4). Neither the effect of response condition nor cue eccentricity was reliable; however, the interaction of these factors was statistically significant [$F(3,12) = 10.85$, $p < .002$]. For manual responses, when the target was eccentric to the cue, costs were greater than when the cue was eccentric to the target [4° pairs, $t(4) = 2.7$, $p = .05$; 8° pairs, $t(4) = 3.9$, $p < .02$]. This pattern of increasing costs with decreasing cue eccentricity has been previously reported (Shulman, Sheehy, & Wilson, 1986; Shulman, Wilson, & Sheehy, 1985). However, the reverse pattern was obtained for saccadic responses: costs were greater when the cue was eccentric to the target [4° pairs, $t(4) = 4.1$, $p < .02$; 8° pairs, $t(4) < 1$, n.s.]. The dissocia-

Table 2
Average Latencies (in Milliseconds) and Standard Deviations for Valid and Invalid Cues for Manual and Saccadic Responses in Experiments 1 and 2

	Experiment 1 Peripheral Cue				Experiment 2 Central Cue			
	Manual		Saccadic		Manual		Saccadic	
	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Valid cues	278	16.5	288	42.4	269	27.0	274	21.4
Invalid cues	318	23.9	328	51.2	311	31.8	317	32.7
Net cost	40		40		42		43	

Table 3
Average Costs (in Milliseconds) and Standard Deviations of Cue-Target Pairs for Each Response Condition in Experiments 1 and 2

	Experiment 1 Peripheral Cue				Experiment 2 Central Cue			
	Manual		Saccadic		Manual		Saccadic	
	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
4° same	35.2	9.3	41.3	10.2	22.8	11.8	23.2	14.9
4° opposite	38.4	6.3	33.4	14.8	44.9	9.5	37.9	19.5
8° opposite	37.9	12.2	40.3	14.6	54.4	12.9	54.3	21.1
12° opposite	56.6	11.9	45.2	11.8	58.1	16.5	60.7	21.8

Table 4
Average Costs (in Milliseconds) and Standard Deviations for 4° and 8° Within-Field Trials as a Function of Relative Cue-Target Eccentricity and Response Condition in Experiment 1

Responses	Cue Eccentric to Target				Target Eccentric to Cue			
	4° Pairs 1:2, 4:3		8° Pairs 1:3, 4:2		4° Pairs 2:1, 3:4		8° Pairs 2:4, 3:1	
	Ave.	SD	Ave.	SD	Ave.	SD	Ave.	SD
Manual	28.4	11.2	26.4	11.7	44.2	15.3	49.5	13.1
Saccadic	53.0	16.3	42.2	13.2	29.0	10.8	38.4	17.3

tion between response conditions was shown by all subjects for the 4° pairs and by 4 subjects for the 8° pairs. Table 4 presents the relevant costs.¹

The dissociation found in the analysis of costs can also be demonstrated by an analysis of the averaged RTs. An ANOVA with cue type, target eccentricity, and response conditions as factors reveals a main effect for cue validity.² In addition, there is a two-way interaction between target eccentricity and response condition [$F(1,4) = 51.8$, $p = .003$] and a three-way interaction [$F(1,4) = 18.79$, $p < .02$]. The two-way interaction reflects faster manual RTs for near than for far targets and an opposite tendency for saccades. The three-way interaction, however, indicates that this effect is due to the invalid cue condition. Paired comparisons using the Newman-Keuls procedure indicate that valid RTs to near versus far targets do not differ for either response condition. However, invalid RTs are faster for near than for far targets in the manual condition, whereas far targets produce faster RTs than near targets in the saccadic condition ($p < .05$). Since far targets are always associated with near invalid cues and near targets are always associated with far invalid cues, this interaction reflects the same dissociation between response conditions seen in the analysis of costs.

SOA analysis. The 40-msec precuing effect evident in the overall data set varied negligibly as a function of SOA. For manual responses, costs at each of the four SOAs (800, 900, 1,000, and 1,100 msec) were 39, 43, 41, and 36 msec, respectively. For saccadic responses, costs were 42, 39, 40, and 41 msec, respectively. The dissociation between response conditions with respect to relative cue-target eccentricity was present at all SOAs.

Anticipations and errors. The set of trials rejected as outliers was analyzed to determine anticipation rates. Saccades with latencies shorter than 125 msec and manual responses faster than 150 msec were designated as anticipations.³ The rate of anticipatory responses was virtually identical in the two response conditions (0.7% for saccades and 0.6% for manual responses). Anticipation rates were arcsine transformed and submitted to an ANOVA with SOA and response condition as factors. While anticipations tended to increase as a function of SOA, neither this nor any other effect was significant. Saccadic errors in which the subjects made a normal latency saccade to the wrong location were extremely rare (0.17%).

Discussion

The premotor hypothesis predicts that the costs observed for manual responses should parallel those obtained for saccades. Although the overall validity effect was equivalent in the two conditions, the relative eccentricity of the cue and target produced significantly different cost patterns. For manual responses, costs were greater when the target was eccentric to the cue than when the cue was eccentric to the target. Shulman et al. (1986) provided evidence suggesting this effect is due to cue eccentricity per se rather than target eccentricity. In any case, the opposite pattern emerged for saccades. In this response condition, the subjects were likely to preprogram a saccade to the cued location. The obtained pattern of costs, therefore, suggested that the subjects were more efficient at increasing than decreasing the amplitude of a prepared saccade. Using similar eccentricities and target displacements in a double-step paradigm, Komoda et al. (1973) also found evidence that lengthening a saccade is performed more efficiently than shortening a saccade (however, see Findlay & Harris, 1984).

The essential point is that a significant divergence in the pattern of saccadic and manual costs was observed. This outcome is inconsistent with the premotor hypothesis of attentional orienting. In addition, contrary to the results of Rizzolatti et al. (1987), invalid cue-target pairs on the same side of the vertical meridian produced costs equivalent to or greater than pairs on opposite sides of the meridian (see Note 1). It is important to note, however, that Rizzolatti et al. used central precues. While some investigators have reported meridian effects with peripheral precues (e.g., Hughes & Zimba, 1985), other investigators have also failed to find them (Egly & Homa, 1991). Thus, the absence of a meridian effect in the present experiment could be due to the use of peripheral precues. Experiment 2 used central precues to evaluate this possibility.

EXPERIMENT 2

Method

Stimulus display. The stimulus display was identical to that used in Experiment 1 with the exception of the precue. Instead of the peripheral cue, a single or double arrow was positioned .5° directly above the fixation point for 300 msec. Arrow direction indicated the likely side of the target. Double arrows indicated an outer location, and a single arrow indicated an inner location.

Apparatus and Procedure. The apparatus and procedure were identical to those used in Experiment 1.

Subjects. Six volunteers with normal or corrected-to-normal vision were paid for their participation.

Results and Discussion

The effect of cue validity on response latency was highly significant [$F(1,5) = 98.02, p < .0004$; see Table 2]. Invalid trials produced an overall cost of 43 msec in both response conditions. As in Experiment 1, an ANOVA was used to evaluate the effects of the four types of invalid cue-target pairs (4° same hemifield, 4° opposite hemifield, 8° opposite hemifield, and 12° opposite hemifield) on the two response conditions. This analysis indicated a highly significant effect of invalid cue-target pair [$F(3,15) = 18.23, p < .0001$] and no effect of response condition. In contrast to results in Experiment 1, a Newman-Keuls test indicated that the costs associated with each of the opposite field conditions, including the 4° condition, were significantly greater than costs in the 4° same-field condition ($p < .05$; see Table 3). The costs for the three opposite field conditions tended to increase with increasing retinal distance between cue and target, but these differences were not significant. A final ANOVA evaluated the effects of the relative eccentricity of the cue and target *within* each hemifield, since these pairs are free of meridian costs. Contrary to results in Experiment 1, relative cue-target eccentricity had no effect on the magnitude of costs for either response system (see Table 5).

The above analyses indicate that with a central cue, in accord with Rizzolatti et al. (1987; see also Hughes & Zimba, 1985, 1987), costs are significantly greater when cue and target occur on opposite sides of the vertical meridian than when they occur on the same side. This was the case for both manual and saccadic responses.

Anticipations and errors. As in Experiment 1, saccades to the wrong location were extremely rare (0.13%) and are not considered further. Anticipations were identified with the criteria used in Experiment 1. The rate for the saccadic condition was 0.7% and the rate for manual responses was 0.8%. An analysis of the arcsine transformed scores indicated that the variation in anticipation rate as a function of SOA differed for the manual and saccadic conditions [$F(3,15) = 5.14, p < .02$]. For the manual-response condition, anticipations increased with increasing SOA (0.26%, 0.69%, 0.95%, and 1.3%), while for saccadic responses the pattern was nonmonotonic (0.69%, 1.12%, 0.26%, and 0.78%). Despite these minor varia-

tions in anticipation rates as a function of SOA, the pattern of greater costs for opposite-field invalid trials than for same-field invalid trials is present for both response conditions at every SOA.

GENERAL DISCUSSION

The present experiments suggest that the relationship between oculomotor programming and attentional orienting may depend on the nature of the precue. With peripheral cues, the vertical meridian had no effect on costs for either response system (cf. Egly & Homa, 1991) and the relative eccentricity of the cue and target had opposite effects on saccadic and manual responses. This dissociation is inconsistent with the premotor hypothesis and suggests that attentional orienting and oculomotor programming may be independent processes. A different picture emerges for central cues. Both saccadic and manual responses are associated with greater costs when the cue and target occur on opposite sides of the vertical meridian than when they occur on the same side. The absence of dissociations between the response conditions and the presence of a meridian effect in both conditions are at least consistent with the premotor hypothesis.⁴ The present results, therefore, suggest that the premotor hypothesis can be a viable account of attentional orienting only in the case of central precues.

Considerable debate surrounds the notion that attention must be reoriented to the target location on invalid trials prior to generating a response (for discussions, see Egly & Homa, 1991; Hawkins, Shafto, & Richardson, 1988; Hughes, 1984; Rizzolatti et al., 1987). However, since the idea of attentional reorienting is integral to the premotor hypothesis, we begin by considering the present outcomes in light of this assumption.

Figure 2 represents three possible ways that precuing effects might operate with saccades and manual responses. These hypothetical schemes all assume that for saccadic responses, reprogramming time contributes in part to the latency difference between valid and invalid trials (e.g., Abrams & Jonides, 1988). In a recent analysis of the effects of spatial precues on visual discrimination, Egly and Homa (1991) accounted for valid-invalid latency differences by a two-stage process that included a delay in target-detection time in addition to a subsequent attentional movement, or reorienting time. According to this view, preliminary detection is more efficient on valid than on invalid trials. This idea is incorporated in the present analyses along with the simplifying assumption that any delay in target detection on invalid trials contributes equally to manual and saccadic responses. Thus, all three schemes include a preliminary detection stage that is common to both responses. Each of these schemes attributes any differences between manual and saccadic conditions to reorienting time, reprogramming time, or both.

Hypothesis A proposes that attention must be reoriented toward the target location before a response can be initiated (Posner, 1980). Thus, reorienting time contributes

Table 5
Average Costs (in Milliseconds) and Standard Deviations for Within-Field Trials as a Function of Relative Cue-Target Eccentricity and Response Condition in Experiment 2

Responses	Cue Eccentric to Target 4° Pairs 1:2, 4:3		Target Eccentric to Cue 4° Pairs 2:1, 3:4	
	Ave.	SD	Ave.	SD
Manual	31.1	16.2	30.5	14.6
Saccadic	25.6	12.8	25.5	15.4

Figure 2. Schematic diagrams of three possible accounts of precuing effects for manual and saccadic responses. The diagrams represent the processing stages that may contribute to response latencies on invalid trials. The first stage represents target detection, which is assumed to be less efficient on invalid than on valid trials. In all schemes, this stage contributes equally to manual and saccadic costs. Any differences between the systems are attributed to saccadic reprogramming, attentional reorienting, or both.

to costs produced by invalid precues for both manual and saccadic responses. However, saccadic costs also include reprogramming time, so this scheme predicts that saccadic costs should be greater than manual costs. In the present experiments, saccadic and manual costs were equivalent with both central and peripheral precues. Thus, there is no simple way in which Hypothesis A can account for the present data.

According to Hypothesis B, saccadic reprogramming and attentional reorienting are the same process. This is the scheme proposed by the premotor hypothesis. This hypothesis predicts that in addition to equivalent overall costs, the *patterns* of costs produced by varying the spatial relation between the cue and target should be the same for manual and saccadic responses. Therefore, Hypothesis B is consistent with the results obtained with central precues, but cannot account for the data obtained with peripheral cues.

According to Hypothesis C, attentional reorienting and saccadic reprogramming are separate processes that occur in parallel. This scheme can accommodate the different patterns of saccadic and manual costs that emerge with peripheral precues, but permits equivalent overall costs for the two responses. Hypothesis C is also consistent with

the effects of central precues, although the meridian effects observed for manual responses with central precues could not be attributed to oculomotor programming. One possibility is that attentional orienting and saccadic programming are separate, but depend on a prior process that is the source of the meridian effects. We return to this idea below.

In Hypothesis C, manual responses depend on attentional reorienting, but saccadic responses do not. As noted above, the idea of attentional reorienting for manual responses has been disputed. However, if the reorienting stage was eliminated for manual responses while the assumption of saccadic reprogramming was maintained, one would expect manual costs to be less than saccadic costs. This effect was not observed in either experiment. It should be noted, however, that the elimination of attentional reorienting for saccadic responses does not mean that saccadic latencies are unaffected by attention. All three hypotheses include the idea that attention affects the efficiency of target detection, which is reduced on invalid trials.

In view of the equivalence of overall manual and saccadic costs, it could be argued that saccades were not preprogrammed in the saccadic condition and that costs

are due to attentional reorienting in both response conditions. We think this is unlikely. In Experiment 1, the dissociation between the response conditions suggests that different mechanisms contributed to the saccadic and manual costs. Saccadic reprogramming is a likely source of costs in the saccadic condition since similar patterns have been found in previous investigations of saccadic programming (e.g., Komoda et al., 1973). If the subjects were preprogramming saccades in Experiment 1 and not in Experiment 2, we would expect saccadic RTs in the valid condition to be faster in Experiment 1 since the latencies in Experiment 2 would include programming time, whereas those in Experiment 1 would not. In fact, saccadic RTs are slightly faster in Experiment 2. In addition, if saccades were preprogrammed in Experiment 1 but not in Experiment 2, we would expect saccadic costs to be larger in Experiment 1 since those costs would include reprogramming time. Yet, the costs in the two experiments were virtually identical.

In summary, it is clear that the pattern of results from neither experiment can be explained simply by a scheme such as Hypothesis A, in which saccadic reprogramming depends on prior attentional reorienting. Only Hypothesis C is able to account for the effect of peripheral precues, but either Hypothesis B or C can account for the data obtained with central precues. Although the present data do not permit us to decide between these alternative accounts of Experiment 2, we will consider other recent findings that are relevant to this issue.

Shepherd and Müller (1989) also reported evidence suggesting that the premotor hypothesis may be more compatible with the effects of central precues than peripheral precues. Using a simple manual response task, they compared the effects of these cue types on the magnitude of attentional costs and benefits at various cue-target SOAs. Peripheral cues were associated with a narrow focus that was maintained across all SOAs. In contrast, central cues produced an initially broad distribution of attention on the cued side, which became more narrowly focused on the cued location with increasing SOAs. They suggest that the central precue results are consistent with the premotor hypothesis in that the initially broad focus could reflect the programming of saccade direction prior to the specification of saccadic amplitude (Rizzolatti et al., 1987).

Shepherd and Müller's (1989) interpretation implies that the nature of the saccadic program is influenced by the type of precue. A recent study of saccade preparation by Abrams and Jonides (1988) also suggests that this may be the case. They report that for voluntary saccades, amplitude and direction may be computed separately, whereas more reflexive saccades appeared to be programmed holistically. The present finding of a meridian effect only for saccades to central cues may, therefore, reflect the independent specification of direction and amplitude for voluntary, cortically mediated saccades, whereas saccades prepared to peripheral precues may reflect more holistic programs mediated by the colliculus (cf. Abrams & Jonides, 1988).

The manner in which saccade direction and amplitude are computed is a matter of ongoing debate (Abrams & Jonides, 1988; Becker, 1989). The work of Abrams and Jonides suggests no difference in the time to program the initial direction or amplitude of a saccade. The time it takes to *modify* these parameters may differ, however, and it is on this possibility that the premotor account of the meridian effects depend. The meridian effect observed in Experiment 2 is consistent with the possibility that amplitude can be modified more rapidly than saccadic direction.

There is, however, at least one recent finding that argues against the premotor hypothesis as portrayed in Hypothesis B. Rafal, Calabresi, Brennan, and Sciolto (1989) reported that inhibition of return, which occurs after any peripheral cue, occurs in response to central precues only if observers are explicitly instructed to prepare a saccade. Covert orienting to symbolic cues is not sufficient to produce inhibition of return. This outcome suggests that saccades are not normally prepared during covert orienting to central cues, if a saccadic response is not required. If this is the case, oculomotor programs cannot be the basis for covert orienting and Hypothesis B must be rejected even in the case of central cues (Klein, 1980; Posner, 1980; however, see Shepherd, Findlay, & Hockey, 1986).

If Hypothesis C is to account for both experiments, the different effects of central and peripheral precues needs to be explained. In particular, the model needs to account for the close correspondence between overt and covert orienting and the meridian effect observed with central precues, as well as the dissociation found with peripheral precues. This implies that some of the components represented in Hypothesis C would have to operate differently with central versus peripheral precues. We offer some speculations as to what these differences might entail.

The independence found with peripheral precues may seem counterintuitive because the sudden onset of such cues seems to elicit a unified orienting response. For example, peripheral stimuli can elicit reflexive saccades and capture attention automatically (Müller & Rabbitt, 1989; Yantis & Jonides, 1984), and inhibition of return occurs when attention is summoned by a peripheral precue (Rafal et al., 1989). However, the finding that attentional and saccadic responses can be triggered by the same stimuli need not imply that these responses are mediated by a common system. If both forms of orienting are elicited automatically by peripheral cues, they may appear to be more interdependent than they actually are (for a similar argument, see Klein, 1980; Rafal et al., 1989; Shepherd et al., 1986). The present evidence for a dissociation between manual and saccadic responses lends credence to this idea. With a peripheral cue, the two responses could be mediated independently and in parallel, since the eccentric stimulus directly specifies a spatial location and produces multiple sensory representations of that location within the visual system. Response-specific effects from peripheral cues could emerge if a representation at the level of the superior colliculus mediates saccadic program-

ming while a parietal representation mediates attentional reorienting.

In contrast, the effects of central precues suggest a closer correspondence between manual and saccadic responses. We suggest that this correspondence may also be related to how the cued location is represented. This means that the processes associated with the first stage in Hypothesis C would operate differently with central and peripheral cues. The computations associated with central precues are likely to be more complex than those associated with peripheral cues, since the expected target location must be derived from an interpretation of the precue. Instead of duplicating these computations, the attentional and saccadic subsystems may use a common representation. This would produce a link between these subsystems that is absent with peripheral cues. The representation of the cued location could, in fact, be the source of the meridian effects for both responses. Attention may be distributed more broadly with central precues (e.g., Shepherd & Müller, 1989), and the major retinal meridians may constitute boundaries between the cortical maps representing these regions of visual space (see Hughes & Zimba, 1987). In Hypothesis C, these boundaries would affect the time course of the target-detection stage, thereby affecting both manual and saccadic responses.

In summary, the premotor hypothesis cannot readily account for the effects obtained with peripheral precues. A model in which attentional reorienting and saccadic programming are separate processes that proceed in parallel is more consistent with these effects. On the other hand, the closer correspondence between covert and overt orienting obtained with central cues is consistent with the premotor hypothesis, although other interpretations are possible. In any case, the varieties of precuing effects attainable with different response measures and different precuing procedures cannot readily be explained by a unitary attentional mechanism. Rather, these effects may reflect a number of component operations related to the nature of the precue and the response requirements of the task.

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NOTES

1. Separate analyses were also performed to evaluate whether either of the two types of same-field pairs (e.g., cue eccentric to target vs. target eccentric to cue) differed from the 4° opposite-field pairs, for either response condition. The only reliable difference between same- and opposite-field pairs to emerge from this analysis was for the saccadic condition. In this case, the same-field costs were *larger* than the opposite-field costs (53.0 vs. 33.4 msec, $p < .05$), a finding opposite to that predicted by the premotor hypothesis. In addition, the within-field pairs differed significantly from each other and in opposite direc-

tions for each response condition as reflected in the cue eccentricity $\times$ response condition interaction reported above.

2. This analysis excludes pairs 1:4, 4:1 and pairs 2:3, 3:2 so as not to confound retinal cue-target distance with eccentricity.

3. A lower anticipation criterion was chosen for the saccadic condition because under some conditions stimulus-driven saccades can be faster than 150 msec (e.g., Kalesnykas & Hallett, 1987; Reuter-Lorenz, Hughes, & Fendrich, 1991). In any case, only one saccadic response fell within the 125-150-msec range.

4. The legitimacy of comparing simple manual and saccadic responses could be questioned because the latter can be considered a choice response. However, as noted in the introduction, the premotor hypothesis offers an account of meridian effects found in a simple RT task in terms of saccadic programming. Thus, an evaluation of this hypothesis requires a comparison of simple RT and saccades. Moreover, the costs associated with simple manual responses and saccades were virtually indistinguishable when central precues were used. This correspondence with central cues suggests that it is not the response measure per se that led to the dissociation with peripheral cues, but rather that the precuing procedures engage different orienting mechanisms.

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