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Hemispheric Control of Spatial Attention

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According to the activation-orienting hypothesis the distribution of attention in space is biased in the direction contralateral to the more activated hemisphere. The present investigation tested this proposal and evaluated the nature of hemispheric differences in orienting control. Activation imbalance was produced by a unilateral visual stimulus. The distribution of attention was measured using a modified line bisection task in which subjects judged the location of an intersect on a tachistoscopically presented horizontal line. The first three experiments suggest that (a) attention is biased in the direction contralateral to the stimulated hemisphere, and (b) the biases do not depend on the task relevance or hemispatial position of the stimulus producing the activation imbalance. The final three experiments suggest that when orienting conflict is introduced the rightward bias becomes more robust than the leftward bias. The findings are consistent with the activation-orienting hypothesis. Each hemisphere generates a contralateral

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attentional bias and the rightward bias of the left hemisphere is stronger. The relevance of these findings to understanding unilateral neglect resulting from parietal damage is discussed.

Animals generally orient to the source of sensory stimulation. In mammals the direction of orienting is determined by neural control networks in the left (LH) and right cerebral hemispheres (RH) that interact in a mutually inhibitory manner (see Kinsbourne, 1974a for review). For example, electrical stimulation of regions controlling eye movements causes gaze to shift contralateral to the stimulated region (Crosby, 1953; Rasmussen & Penfield, 1947). Conversely, unilateral lesion produces ipsilesional turning of the eyes and/or head (DeRenzi, Colombo, Faglioni, & Gibertoni, 1982). Stimulation of one side or inhibition of the other produces the same effect on orienting: the shift is contralateral to the more activated region.

Such observations led to a general theory that proposes a fundamental relationship between activation asymmetries and the control of lateral orienting (Kinsbourne, 1970a,b; Trevarthen, 1972). An asymmetrical increase in hemispheric activation, however generated, can elicit contralateral attention and gaze shifts. This theoretical position, which shall be referred to as the activation-orienting hypothesis, led to numerous studies with two general aims. Studies have used lateral eye movements to index arousal asymmetries in order to determine the hemispheric contributions to various cognitive and affective processes (e.g., see Hiscock, 1986 for review). Other studies evaluated the role of attentional factors in perceptual asymmetries (e.g., Boles, 1979; Hellige & Cox, 1976; Kinsbourne, 1970a, 1977; Kinsbourne & Byrd, 1985; Klein, Moscovitch, & Vigna, 1976). This work examined the effects of selective hemispheric activation, produced by verbal or spatial tasks, on the magnitude and direction of visual field differences.

Despite its direct relevance to the issue, the activation-orienting hypothesis has not been tested specifically as an account of how the hemispheres contribute to the control of spatial attention. The hypothesis predicts that even in the absence of eye or head movements there will be a bias to orient attention in the direction contralateral to the more activated hemisphere. The present investigation tested this account of attentional orienting in normal subjects.

The cognitive task methodology (i.e., verbal versus spatial tasks) for altering hemispheric activation, revealing though it is, is encumbered by intertask and intersubject variability (e.g., Hellige, Cox, & Litvac, 1979; Levy, Heller, Banich, & Burton, 1983). Furthermore, the multicomponential nature of even simple cognitive tasks leaves open the possibility that not all components are lateralized to the same hemisphere. Over an epoch of electroencephalographic recording, a task may produce greater net activation of one hemisphere (Ehrlichman & Weiner, 1979; Galin & Ellis, 1975; see also Gur & Reivich, 1980). This does not guarantee that at all times during the epoch the magnitude and direction of asymmetry are the same. Therefore orienting biases produced by such manipulations may best be reflected in sustained scanning or exploratory biases (Levy & Kueck, 1986). To examine time-locked, phasic changes in the direction of covert orienting (Posner, 1980), we chose an alternative approach.

Unilateral visual stimulation produces asymmetrical hemispheric activation (Davidson, Schaffer, & Saron, 1985) but has not yet been used to assess the effects of activation imbalance on spatial orienting. Lateralization of simple sensory stimuli can be precisely controlled, thereby allowing experimental manipulation of the balance of hemispheric activation. This method does not depend on assumptions about time course or about the extent to which the cognitive demands of a task differentially engage the hemispheres.

Lateralized visual input will produce an activation imbalance in favor of the hemisphere that is stimulated directly. According to the activation-orienting hypothesis, attention should shift contralateral to the stimulated hemisphere. Presenting a stimulus to the right visual field (RVF) should produce greater LH activation and a concomitant orienting shift to the right. A leftward shift should result from left visual field (LVF) presentations. Furthermore, the spatial distribution of attention should vary even when the stimulus eliciting the activation asymmetry is not relevant to the subject's task. It is the activation asymmetry produced by a lateralized stimulus that underlies the attention shift and not necessarily the strategic deployment of attention to that event. In this way the attentional response of the subject will have an involuntary or automatic component (Jonides, 1980).

It is important to note that the activation-orienting hypothesis predicts a directional orienting bias rather than a bias to orient to an absolute region of space. When the balance between the opposing lateral control systems shifts, one set of directional vectors is favored over another. The result is that, within a visual field, hemispace, or across the body midline, the tendency to orient in the direction contralateral to the more activated hemisphere should predominate.

The first three experiments tested and supported these predictions. Building upon these results, the final three experiments examined hemispheric differences in the control of spatial attention.

ASSESSING THE DISTRIBUTION OF ATTENTION

The plan of the present study was to alter the perception of a neutral stimulus by manipulating the hemispheric balance of activation. The stimulus used was a horizontal line and the attribute of interest was the apparent relative lengths of the two segments formed by a perpendicular intersect. Line bisection is known to reflect impairments in spatial attention due to lateralized brain damage (Heilman & Valenstein, 1979; Schenkenberg, Bradford, & Ajax, 1980). The performance on this task of both patients and control subjects is affected by variables such as cuing which are designed to manipulate the direction of attention (Riddoch & Humphreys, 1983; Reuter-Lorenz & Posner, in press). The standard bisection task requires the subject to draw an intersect at the midpoint of a horizontal line. The direction and magnitude of deviation of the subjective midpoint from the veridical midpoint reflect the subject's attentional bias. When, for example, the subject places the intersect to the right of the actual center this indicates that he has underestimated the left side or overestimated the right.[1] While separating these effects empirically is problematic, either one suggests that attention is relatively biased toward the rightward extent of the line. Leftward displacement of the intersect indicates the opposite attentional bias. The standard bisection task requires a motor response and therefore confounds perceptual and motor biases. But even when the motor response component of the task is eliminated, bisection judgments can reflect attentional biases or left neglect in patients with right hemisphere damage (Reuter-Lorenz & Posner, in press).

For the present investigation the bisection task was modified specifically to examine the perceptual effects of asymmetrical hemispheric activation. Horizontal lines were exposed individually at various locations in the viewing field. Each line was transected by a small vertical line positioned exactly at midpoint or displaced to the right or left of midpoint. Subjects reported whether the intersect was at center or to the left or right of center. The spatial distribution of attention was inferred from the pattern of errors made in these bisection judgements (see below).

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[1] The traditional interpretation of bisection performance in general and the performance of neglect patients in particular have been based on the following reasoning. The midpoint of a line defines the boundary of two equal segments. Thus we can infer that when an individual selects their subjective midpoint they have created two segments which are subjectively equivalent. When the subjective midpoint lies to the right of the actual midpoint, the subject has created a right segment which, objectively, is shorter than the left. However, the subject has informed us that subjectively these two segments are equivalent. Presumably, this subjective equivalence could only be achieved if the length of the right segment has been overestimated or the left has been underestimated. This logic will be applied to interpret errors in bisection judgements in the present experiment (cf. Bradshaw, Nettleton, Pierson, Nathan, & Wilson, 1987). Our method cannot specify whether the directional bias results from overestimation of one side or from underestimation of the other. Our convention will be to describe the biases as relative underestimation of one of the segments.

EXPERIMENT 1

This experiment examined the influence of stimulus-induced activation asymmetries on spatial attention by assessing performance on a lateralized visual line bisection task. Horizontal lines were presented tachistoscopically to the LVF or RVF. The stimulus that created the activation imbalance was also used to measure the attentional bias. According to the activation-orienting hypothesis attention is directed contralateral to the more activated hemisphere. The errors in bisection judgements should reflect a rightward attentional bias when stimuli are viewed in the RVF and the opposite pattern of bias is predicted for LVF presentations. If lateralized stimulus exposure does not influence orienting no biases should emerge in either visual field and errors should be random.

In contrast, if visual acuity and visual angle determine performance, it would be the portion of the line closer to the fovea that would receive stronger sensory representation. The pattern of errors would reflect a leftward bias in the RVF and rightward bias in the LVF, the opposite to that predicted by the activation-orienting hypothesis.

Schema for Interpreting Errors

The following schema is used to interpret the different patterns of errors which occur on this task (refer to Fig. 1). In this and in all subsequent experiments subjects were shown lines with left, middle, or right intersects and reported the intersect's location. In the absence of any bias, when attention is distributed evenly across the line, errors should be random. Thus there should be no difference in accuracy for right and left intersects, and middle intersects should be mistaken for left or right intersects equally often.

An attentional bias would cause the errors to be systematic. A rightward bias would make the left side of the line appear shorter than the right side. Thus, a right intersect may appear to be in the middle or even to the left. Accordingly, a middle intersect would seem closer to the left endpoint and left intersects would appear to be more clearly leftward than they actually are. A leftward bias would produce the opposite pattern of errors.

On the basis of this schema two scores were computed for each subject. A right shift (RS) score was computed by counting the number of times a right intersect was mistaken for a middle or left intersect and the number of times a middle intersect was mistaken for a left intersect. The sum of these errors was divided by the total number of trials for that viewing condition. Left shift (LS) scores were similarly computed.

The presence of a bias and its direction are indicated by the statistical comparison of the average right and left shift scores obtained in each condition. When there is no overall bias, the two shift scores should be

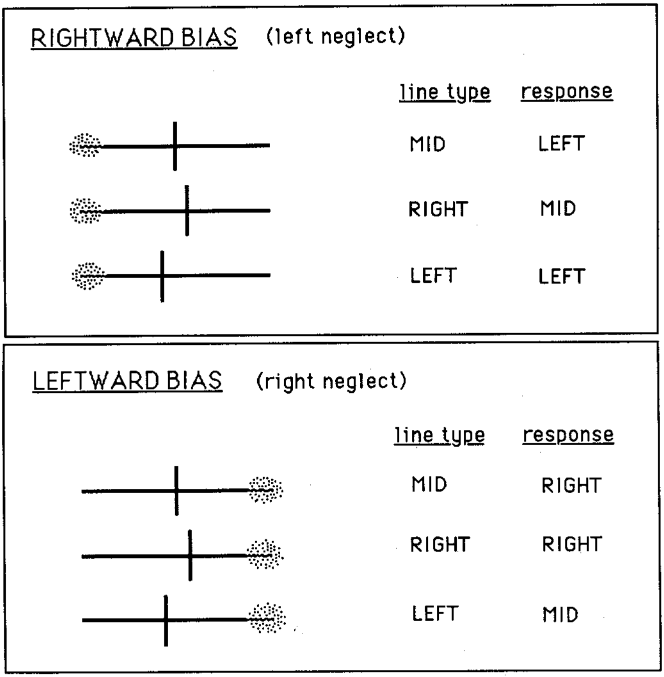

FIG. 1. Schema for interpreting errors on bisection task. Speckled regions represent unattended portions of lines.

approximately equal. If the left shift score is significantly greater than the right shift score, a leftward bias would be indicated. A right bias is indicated by the opposite pattern. The proportion of overall errors for each viewing condition can be derived from the sum of the left shift and the right shift scores for that condition.

Method

Subjects. Eight undergraduates from introductory psychology participated for course credit. All subjects were right-handed by self-report and had normal or corrected to normal vision.

Apparatus. In this experiment, as in all subsequent experiments, lines were viewed in a two-field Cambridge tachistoscope with a background luminance level of 32 cd/m^2. The preexposure field had a fixation dot in the center of the screen. The point did not correspond to the center of any of the stimulus lines and therefore did not assist subjects with their bisection judgements.

Materials. For each condition (LVF and RVF) a set of six stimulus cards was constructed. Each 4 × 6-in. card contained a fixation point that corresponded to the center of the viewing field. A single horizontal line, 2 cm in length and 0.5 mm thick, was drawn with a black felt tip pen. Its midpoint was 2 cm to the right or left of the fixation point. At a viewing distance of 36 cm, the lines subtended a visual angle of 3.2°. The inner endpoint was 1.6° from fixation.

An intersect was drawn perpendicularly through each line. The intersect was 1 cm long and was bisected by the horizontal line. For each set, two intersects were exactly at center, two were 1 mm to the left of center and two were 1 mm right of center.

Procedure. The LVF or RVF conditions were blocked and presented in a counterbalanced order across subjects. The subjects' task was to judge whether the intersect was in the center of the line or to the left or right of center. Subjects verbally reported where the intersect appeared. They were told that there would be an equal number of intersects in each position. Prior to each stimulus onset the experimenter signaled the subject to fixate centrally. Stimuli were presented for 130 msec. Pilot work indicated that subjects performed at approximately 70% accuracy with this exposure duration. All responses were recorded manually by the experimenter. Eight practice trials preceded each viewing condition. Each stimulus set was presented eight times in a random order for a total of 48 trials in each condition. A short break was given between conditions.

Results

A two-way analysis of variance (ANOVA) with visual field and shift direction as within-subject factors indicated a significant interaction and no significant main effects. The interaction of visual field and shift direction indicated that the error pattern varied systematically as a function of which hemisphere received the stimulus, $F(1, 7) = 28.01$, $p < .001$. The RS and LS values associated with the LVF and RVF conditions are displayed in Table 1. It is evident that LS is greater than RS for the LVF condition, $t(7) = 4.02$, $p < .01$. This pattern is consistent with the presence of a leftward attentional bias which would be expected if RH activation produces a contralateral shift of attention. The reverse pattern obtains for RVF exposure, $t(7) = 3.43$, $p < .01$, consistent with the prediction that LH activation produces a rightward orienting shift.

Discussion

The error pattern associated with each hemifield is consistent with the predictions of the activation-orienting hypothesis. When the line was in the RVF, errors reflected left side underestimation, which is expected when the right extent of the line is better attended than the left. The

TABLE 1
MEAN SHIFT SCORES FOR EXPERIMENT 1

	Shift direction	
Viewing condition	Left (LS)	Right (RS)
LVF		
M	.35	.08
SD	(.12)	(.07)
RVF		
M	.11	.34
SD	(.06)	(.09)

Note. Shift scores are expressed in proportions formed by dividing the number of left shift or right shift errors in a given condition by the number of trials for that condition.

opposite distribution gradient occurred when the line was in the LVF; attention was biased to the left with relative underestimation or neglect of the right.

If the different patterns of error in each visual field resulted from activation asymmetry produced by lateralized visual input, then the biases should depend on the retinotopic location of the stimulus producing the activation imbalance and not necessarily its spatiotopic or egocentric position. The first experiment confounded retinotopic, spatiotopic, and egocentric frames of reference. LVF stimuli appeared on the left of the visual display and left of the body midline and likewise for RVF stimuli. The next experiment held the spatiotopic and egocentric position of the stimulus constant. The location of the fixation point was varied so that the same physical stimulus fell on the left or right hemiretina. If hemispheric activation imbalance determines the spatial distribution of attention then the results from Experiment 1 should replicate.

EXPERIMENT 2

To vary the retinotopic location of the stimulus while holding spatiotopic and egocentric position constant, the lines appeared centrally while the subject fixated a point to the right or left of midline. When subjects fixated the left point, the stimulus at the screen's midline fell into the RVF and vice versa for right fixations. These conditions will be referred to as the lateral fixation or LFIX conditions (i.e., LFIX-RVF, LFIX-LVF). The standard hemifield exposure conditions used in the first experiment were also included in the present experiment and will be referred to as the central fixation or CFIX conditions (i.e., CFIX-RVF, CFIX-LVF).

Method

Subjects. Eight new right-handed introductory psychology students participated in this experiment.

Apparatus. The only change was in the LFIX conditions where the preexposure field had a fixation point placed 6.4° laterally to the left or right. The point did not correspond to the center of any of the stimulus lines and therefore did not assist subjects with their bisection judgements.

Materials. For the CFIX conditions stimuli were the same as those in the first experiment except that lines were 4 cm in length and the intersects were either at center or displaced to the right or left of center by 1 or 2 mm (0.16 and 0.32°, respectively). At a viewing distance of 36 cm, the lines subtended a visual angle of 6.4°. The inner endpoint was 3.2° from fixation.

For the LFIX conditions all lines were drawn with their midpoints corresponding to the center of the screen. For LFIX-LVF, a fixation point was drawn on the card 4 cm (6.4°) to the right of the line's center; for LFIX-RVF the fixation point was 4 cm to the left of center.

Procedure. Again the subject's task was to determine whether the intersect was at the left, right, or center of the line. The central fixation conditions were performed first and in the same order as in the first experiment.[2] Thirty-two trials comprised the LVF and RVF conditions. Fifty percent of the trials had center intersects, and the other 50% divided equally among left and right intersects. For the two lateral fixation conditions (48 trials each), lines were centered on the screen, and a point 6.4° left or right of center was fixated. The order of the RVF and LVF conditions was counterbalanced between subjects. The instructions and exposure durations were the same as those in Experiment 1. Eight practice trials preceded each condition.

Results

A striking similarity is evident between the pattern of errors for the central and lateral fixation conditions. This was confirmed statistically by a three-way ANOVA with fixation condition, visual field, and shift direction as repeated, within-subject factors. The only effect to reach significance was a visual field by shift interaction, $F(1, 7) = 103.06$, $p < .001$, which indicated that the direction of bias varied reliably with the visual field of presentation, regardless of fixation condition (see Table 2). In both fixation conditions LVF presentations produced greater LS than RS scores, [LFIX, $t(7) = 3.58$, $p < .01$; CFIX, $t(7) = 5.27$, $p < .01$] whereas for RVF presentations RS was greater than LS [LFIX, $t(7) = 5.27$, $p < .01$; CFIX, $t(7) = 6.96$, $p < .001$].

Discussion

The patterns of attentional bias did not differ between the central and the lateral fixation conditions. The biases do not depend on the spatiotopic or egocentric placement of the stimulus that elicits the activation asymmetry. The results from the first two studies are consistent with the proposal that an asymmetrical increase in hemispheric activation can produce a contralateral shift of attention.[3]

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[2] Four-centimeter lines presented foveally were associated with a leftward bias or relative underestimation of the right segment. No biases emerged for foveal presentations when the lines were 2 cm in length unless attention was manipulated experimentally (e.g., see Experiments 4 and 5). As line length increases so might the demand for RH spatial abilities, which could in turn produce a leftward bias (Kinsbourne, 1970b; see Bradshaw et al., 1987). The aim of this investigation was to examine the effects of attention on a stimulus that was not normally associated with an attentional bias. Therefore the 2-cm lines were used in all subsequent studies, and Experiment 1, which had been run originally with 4-cm lines, was rerun with 2-cm stimuli. Line length did not effect the results from the lateralized viewing conditions.

[3] When letter strings are presented under parafoveal viewing conditions, a perceptual advantage has been found for peripheral items compared to items occurring nearer the fovea (e.g., Banks, Larson, & Prinzmetal, 1979; White, 1976). The present findings suggest that this serial position effect could be an example of the general tendency to allocate attention toward the periphery under lateralized exposure conditions. An attentional account of this effect would not be incompatible with the directional feature migration and masking accounts that others have proposed (Krumhansl, 1977; Wolford, 1975) and it is consistent with the scanning account proposed by White (1976). An attentional account could also explain the occurrence of the serial position effects under conditions where masking and migration accounts have not predicted them (see Chastain, 1981).

TABLE 2
MEAN SHIFT SCORES FOR EXPERIMENT 2

Viewing condition	Shift direction: Left	Shift direction: Right
Central fixation		
LVF		
M	.32	.07
SD	(.15)	(.06)
RVF		
M	.05	.38
SD	(.04)	(.06)
Lateral fixation		
LVF		
M	.26	.09
SD	(.11)	(.03)
RVF		
M	.08	.33
SD	(.02)	(.08)

Note. Shift scores are expressed in proportions formed by dividing the number of left shift or right shift errors in a given condition by the number of trials for that condition.

In Experiments 1 and 2 the stimulus which elicited the activational imbalance was essential to the subject's task. However, if the attentional biases are due to activation asymmetry, they should not depend on the task relevance of the stimulus. The following experiment tested this idea. Rather than using the line stimulus to activate the hemispheres and measure the bias, an irrelevant stimulus was presented unilaterally while the line itself was foveated.

In the first of two conditions, subjects ignored the lateral stimulus while performing the bisection task with foveally presented lines. The irrelevant stimulus was a square in the periphery that either did or did not contain a dot. In the second condition subjects attended to the square, reporting the presence or absence of the dot while simultaneously performing the foveal bisection task. Unilateral stimulation should bias attention even in the "ignore" condition because activation asymmetries should influence orienting independently of the subject's intentions.

EXPERIMENT 3A

Method

Subjects. Sixteen new right-handed students from introductory psychology participated in this experiment. The number of subjects was increased over the previous two experiments in order to obtain a sufficient number of observations given an easier task and a corresponding drop in error rate.

Materials. Lines were 2 cm in length (approximately 3.2°) with intersects in the center or 1 mm to the left or right. The midpoint of the line corresponded to the center of the screen. Each card also contained a small square (0.5 × 0.5°) which was displaced 1 cm (1.6°) laterally from the right or left endpoints of the line. For each of the three intersect positions, two cards had a left square and two had a right square. For each side one square contained a dot and one was empty.

The lines were centered on the screen and central fixation was required. However, no fixation point was present because it would have served as a marker for the midpoint of the line. To encourage central fixation subjects were required to report a small digit (0.48 × 0.32°) which was presented occasionally and without warning in the center of the screen. Subjects were informed that if they failed in this report on more than two trials the experiment would be terminated.[4] One was excluded on this basis.

Procedure

Subjects participated in two instructional conditions: ignore and attend. For the first two blocks of trials subjects ignored the squares. Trials were blocked according to the side on which the square appeared. There were 48 trials per block, composed of 16 trials for each of three intersect positions. The order of square position was counterbalanced between subjects so that half of them ignored the left square first and half ignored the right square first. For the second two blocks of trials, subjects attended to the laterally placed square and reported whether it contained a dot. The line bisection task was said to be of primary importance, but both tasks were to be performed as accurately as possible. Subjects first reported the presence or absence of the dot and then the intersect location. Eight practice trials preceded each block.

Exposure duration. As compared to the first two studies, subjects performed more accurately on the bisection task in this and in all subsequent experiments presumably because the line and intersect were foveated. In order to avoid ceiling effects and to maintain comparable performance levels exposure duration was adjusted for each subject individually.

For the ignore condition, the experimental trials began at an exposure duration of 60 msec. The duration was then adjusted every 12 trials in accordance with the subject's performance level. For less than three errors the exposure duration was decreased by 20 msec; for four or more errors duration was increased by 20 msec. The same procedure was used for the attend condition, but the initial duration was 80 msec. The average exposure duration was 39 msec for the ignore conditions and 69 msec for the attend conditions (range 10–130 msec).

Detection task. The dot detection task was included to manipulate the direction of attention. To keep bisection performance at approximately 75% accuracy and the exposure duration under 150 msec, the detection task was made easy. Accuracy averaged about 98% in all conditions with virtually no variation. For these reasons the data from this task will not be discussed.

Results

A three-way ANOVA, with instruction, visual field, and shift direction as repeated, within-subject factors, was computed for the shift scores. The main effect of instruction was significant, $F(1, 15) = 18.56$, $p <$

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[4] The strongest incentive for maintaining fixation was the fact that the line stimulus would be centered on the screen. Since bisection was of primary importance it was thought that subjects would comply with the fixation instructions. The numerical control was added as a safeguard and to provide the subject with a periodic reminder of the position of central fixation.

.001, indicating that bisection accuracy was higher in the ignore than in the attend condition. The significant interaction of visual field and shift direction, $F(1, 15) = 73.56$, $p < .001$, indicates that, regardless of the instruction to ignore or attend to the lateral square, it systematically influenced performance. When the square was presented to the LVF, LS was significantly greater than RS, $t(15) = 3.93$, $p < .01$. When it appeared in the RVF, RS was significantly greater than LS, $t(15) = 4.58$, $p < .01$, (see Table 3).

The only other effect to reach significance was the three-way interaction between instruction, visual field, and shift, $F(1, 15) = 25.76$, $p < .001$. For each visual field, instruction had a differential and selective effect on the LS and RS scores. This effect is illustrated by a comparison of the LS and RS scores for the LVF under the two instruction conditions (Table 3). When subjects were ignoring the LVF square, RS equaled .03, whereas LS equaled .12. Attending to the LVF square did not changed RS (.03). However, LS increased to .18, $t(15) = 3.78$, $p < .01$. The selective effect of instruction on shift scores was also apparent for the RVF square. In this case the LS score showed no change while RS increased significantly from .12 to .22, $t(15) = 6.96$, $p < .01$.

Discussion

For both the ignore and the attend conditions the direction of bias depended on which hemifield was stimulated by the square. The instruc-

TABLE 3
MEAN SHIFT SCORES FOR EXPERIMENT 3A

	Shift direction	
Instruction condition	Left	Right
Ignore		
LVF		
M	.12	.03
SD	(.09)	(.04)
RVF		
M	.03	.12
SD	(.03)	(.09)
Attend		
LVF		
M	.18	.03
SD	(.11)	(.03)
RVF		
M	.03	.22
SD	(.10)	(.04)

Note. Shift scores are expressed in proportions formed by dividing the number of left shift or right shift errors in a given condition by the number of trials for that condition.

tion to ignore or attend to the squares significantly affected the magnitude but not the direction of the biases. The evidence of directional biases even in the ignore conditions is consistent with the hypothesis that lateralized stimulation elicits an orienting shift regardless of stimulus relevance.

There are good reasons to believe that subjects attempted to ignore the squares when told to do so. All participated in the ignore condition first and were given no indication that the squares would subsequently be relevant. Furthermore, the performance in the ignore and attend conditions differed significantly, which would not be expected if subjects were deliberately attending to the square in the ignore condition.

The difference between the ignore and the attend conditions was not simply in overall error rates. Only errors indicative of a contralateral bias increased in the attend condition; the others were unaffected by the detection task. The deliberate allocation of attention to the laterally placed stimulus accentuated the bias produced by the mere presence of the stimulus.

While the results of the present experiment are consistent with the activation-orienting account, an alternative explanation for Experiment 3A must be considered. It is possible that subjects may have been inadvertently pooling or grouping the sensory information from the line and the box into one perceptual object (e.g., Kahneman & Henik, 1981). When attempting to judge the line's center their estimates reflected the center of the combined box-line percept, which would produce the observed pattern of bisection errors. By this account the effect of the instruction manipulation would reflect the differential weighting of the square in the combined percept depending on whether or not the square was attended.

A pooling strategy of this type may also be relevant to Experiment 1 where the edge of the screen could have been pooled with the line thereby yielding the observed pattern of bisection errors in each visual field. This account, however, cannot explain the fact that the biases persist in Experiment 2 when the line is equidistant from additional, irrelevant objects. Furthermore, the pooling argument does not predict any right/left asymmetries in the magnitude of the bisection biases. The subsequent experiments demonstrate that such asymmetries can emerge under certain exposure conditions, thereby posing a serious challenge to a pooling account for the effects observed in Experiment 3A.

DISCUSSION OF EXPERIMENTS 1–3A

The results from the first three experiments are consistent with the hypothesis that a contralateral attention bias emerges under conditions designed to produce asymmetrical hemispheric activation. In the conditions examined thus far there were no differences in the magnitude of the right and left attentional effects. There are reasons to expect, however, that under other conditions hemispheric differences may emerge.

The control of spatial attention may differ for the two cerebral hemispheres. Unilateral neglect, a neurological disorder that involves a deficit in spatial orienting (e.g., Baynes, Holtzman, & Volpe, 1986; Posner, Walker, Friedrich, & Rafal, 1984), is more common and more severe following right parietal damage than following left parietal damage (DeRenzi, 1982). Kinsbourne (1970b, 1987) has explained this asymmetry in the following way. Lateralized brain damage decreases the arousal of the affected hemisphere. Consequently, the activation imbalance favors the intact hemisphere and its orienting bias dominates. If the normal orienting biases of each hemisphere were equivalent no asymmetrical effects of right and left brain damage would be expected. The preponderance of left neglect is consistent with the idea that the rightward bias of the LH is stronger than the leftward bias of the RH (e.g., Kinsbourne, 1974b).

Orienting conflict or uncertainty may be important to the expression of hemispheric differences. According to the activation-orienting hypothesis rivalry exists between the left and the right orienting tendencies because the hemispheric centers controlling directed attention are in opposition. Under conditions of directional uncertainty, the increased opposition between control centers may reveal hemispheric differences in orienting strength.

Orienting uncertainty is also known to increase the effectiveness of attentional cues. Posner, Snyder, and Davidson (1980) report that under blocked cuing conditions attentional effects are weaker than when cues are randomized (see also Muller & Findlay, 1987). Randomized stimulus location requires the active selection of a spatial location on each trial.

Thus far in the present investigation, stimuli have been blocked so that the lateral stimulus appeared in the same visual field for a series of trials. If subjects could not anticipate where the square would appear, a rivalry between the right and the left orienting tendencies might be engendered and hemispheric differences expressed. This was the rationale for the next experiment.

The method used in Experiment 3A was used again in Experiment 3B except that the location of the lateralized stimulus was randomized rather than blocked. If the rightward bias is stronger than the leftward bias, this difference should be expressed when the location of the activating stimulus is unpredictable.

EXPERIMENT 3B

Method

Subjects. Sixteen new right-handed subjects participated in this experiment.

Stimulus materials. The stimulus materials were the same as those in Experiment 3A.

Procedure. The procedure was the same as that in Experiment 3A except that LVF and

RVF squares were presented in a random rather than blocked order. The two instruction conditions comprised two blocks of 48 trials with an equal number of LVF and RVF squares presented in a mixed order. A new random order was used for each subject.

Exposure duration. Adjustments were made as in Experiment 3A. The average duration was 49 msec for the "ignore" conditions and 73 msec for the "attend" conditions. Durations ranged from 10 to 130 msec.

Results

A three-way ANOVA with instruction, visual field, and shift direction as repeated factors revealed four significant effects. A main effect for instruction again indicated higher shift scores when subjects were attending to the lateral squares than when they were ignoring them, $F(1, 15) = 27.91$, $p < .001$. A main effect for visual field showed that shift scores were higher for RVF squares than for LVF squares, $F(1, 15) = 8.41$, $p < .01$.

The shift scores were reliably affected by the visual field in which the square was presented, $F(1, 15) = 88.70$, $p < .001$. Thus as in Experiment 3A, contralateral biases emerged regardless of the instruction to attend or ignore the lateral squares (see Table 4).

The significant three-way interaction again indicated that instruction influenced the magnitude of the bias produced by the LVF and RVF squares, $F(1, 15) = 8.69$, $p < .009$, (see Table 4).

In all important respects, save one, these data replicate the effects found in Experiment 3A. The major difference is the main effect for visual field found in the present study. The means in Table 4 indicate

TABLE 4
MEAN SHIFT SCORES FOR EXPERIMENT 3B

Instruction condition	Shift direction Left (LS)	Right (RS)
Ignore		
LVF		
M	.16	.02
SD	(.11)	(.03)
RVF		
M	.03	.19
SD	(.03)	(.12)
Attend		
LVF		
M	.20	.04
SD	(.12)	(.02)
RVF		
M	.05	.29
SD	(.06)	(.07)

Note. Shift scores are expressed in proportions formed by dividing the number of left shift or right shift errors in a given condition by the number of trials for that condition.

that this effect is due primarily to the size of the RS score for the RVF. This effect was not apparent in Experiment 3A which suggests that randomizing may have selectively increased the magnitude of the RS score and therefore the rightward bias.

To test this idea further, a four-way ANOVA was computed on the data from Experiments 3A and 3B, with condition (blocked versus mixed) as a between-subject factor. All of the main effects and interactions which were significant when the experiments were analyzed separately were again significant in the combined analysis. The effect of interest is the interaction of condition, VF, and shift direction. Although this effect fell just short of significance, $F(1, 30) = 3.516$, $p < .067$, the trend was in the predicted direction.

Table 5 presents the shift scores for each visual field for Experiments 3A and 3B, collapsed across instruction. The only salient change is the significant increase in RS for the RVF in the mixed compared to the blocked condition, $t(30) = 2.95$, $p < .01$. Thus, the marginally significant difference between mixed and blocked conditions that emerges in the ANOVA is due to the stronger rightward bias produced by the RVF stimulus in the mixed condition.

Discussion

The findings of Experiment 3B suggest an asymmetry in attentional control. Differences in the effect of LVF versus RVF stimulation emerged

TABLE 5

MEAN SHIFT SCORES FOR EXPERIMENT 3A AND 3B COLLAPSED ACROSS INSTRUCTION

	Shift direction	
Viewing condition	Left (LS)	Right (RS)
Experiment 3A (blocked)		
LVF		
M	.15	.03
SD	(.11)	(.03)
RVF		
M	.03	.17
SD	(.04)	(.11)
Experiment 3B (mixed)		
LVF		
M	.18	.03
SD	(.12)	(.03)
RVF		
M	.04	.24
SD	(.05)	(.11)

Note. Shift scores are expressed in proportions formed by dividing the number of left shift or right shift errors in a given condition by the number of trials for that condition.

when the spatial locus of the lateral stimulus was unpredictable. The rivalry between the LH and the RH control centers was increased when the locus of stimulation could not be anticipated. The rightward bias was significantly accentuated under these conditions, whereas the leftward bias was not affected.

The accentuation of the right bias under randomized versus blocked conditions was limited in magnitude. In the experiment that follows a further effort is made to induce orienting uncertainty and differential bias strength. Subjects did not know if they would have to orient to the periphery or maintain attention at midline. For a block of trials the square appeared randomly in one visual field only or not at all. The subject's task was to report whether a square was present and to report the location of the intersect. The materials from the previous experiment were used again and location uncertainty was introduced by intermixing cards with and without lateral squares.

EXPERIMENT 4

Method

Subjects. Sixteen right-handed subjects participated in this experiment.

Materials. The stimuli were from Experiment 3A. Cards with lateral squares containing dots and a set without squares were used.

Procedure. Subjects participated in four lateral detection blocks (48 trials per block) in which they reported the presence or absence of a lateral square, in addition to performing the bisection task. Half of the subjects detected the right square first; the other half detected the left. It was stressed that if the square was not on the specified side, it was nowhere on the card. Subjects were informed that on any given trial it was equally likely that a square would be present or absent.

Exposure duration. The exposure duration was adjusted by the method previously described. The average duration that resulted was 43 msec for the no square condition and 46 msec for the attend conditions (range 10–130 msec).

Results

The data were analyzed using a three-way ANOVA with square (present versus absent), visual field, and shift direction as repeated, within-subject factors. Several significant effects emerged. A significant main effect for visual field, $F(1, 15) = 7.10$, $p < .02$, indicated higher shift scores for RVF than for LVF presentations. The interaction of square and shift score was significant, $F(1, 15) = 17.23$, $p < .001$. There was no overall difference between RS and LS when the square was absent, but an overall greater RS than LS when it was present. The interaction of visual field and shift was also significant, $F(1, 15) = 6.52$, $p < .02$. RS was greater than LS for the RVF condition, whereas there was little difference between these scores in the LVF condition (see Table 6).

Finally, the three-way interaction among square, visual field, and shift direction was also significant, $F(1, 15) = 40.99$, $p < .001$. Table 5 indicates that when the square is present the pattern demonstrated in the first three experiments emerges again for both visual fields. However, the bias elicited by the right square is clearly greater than that elicited by the left square.

When the lateral square was absent the difference between RS and LS diminished for both visual fields. For the LVF, LS and RS were virtually identical, $t(30) = 1.03$, $p > .05$. For the RVF, LS was significantly larger than RS, $t(30) = 2.06$, $p = .05$.

Discussion

Under the present conditions of directional uncertainty, the orienting bias produced by the RVF square was greater than the bias associated with LVF stimulation. As in the previous experiment, the right bias of the LH was found to be more robust than the RH's leftward bias.

The present findings also underscore the power of the lateralized visual stimulus to elicit orienting. Without the lateralized stimulus contralateral biases were not expressed by either hemisphere. This suggests that when both hemispheres are stimulated simultaneously conflict would be maximized. Bilateral stimulation should also elicit differential orienting strength.

The following experiment examined the effects of sensory competition on the strength of the right and left biases. Squares were presented on both sides of a centrally placed line, one in each visual field. Subjects

TABLE 6

MEAN SHIFT SCORES FOR EXPERIMENT 4

	Shift direction	
Viewing condition	Left (LS)	Right (RS)
Square present		
LVF		
M	.08	.03
SD	(.06)	(.03)
RVF		
M	.02	.19
SD	(.13)	(.03)
Square absent		
LVF		
M	.09	.11
SD	(.07)	(.09)
RVF		
M	.12	.08
SD	(.06)	(.08)

Note. Shift scores are expressed in proportions formed by dividing the number of left shift or right shift errors in a given condition by the number of trials for that condition.

detected the dot in one of the two lateral squares and ignored the other square for an entire block of trials. We know from Experiment 3A that even when subjects are instructed to ignore a lateralized square the distribution of attention is biased. Therefore if lateralized visual stimulation is delivered to both hemispheres simultaneously, it is likely that they will compete for attentional control.

The experiment that follows pits the directional orienting responses of the LH and RH against each other. By requesting subjects to ignore the irrelevant square, the ability to inhibit one orienting tendency in favor of the other can be evaluated.

EXPERIMENT 5

Method

Subjects. Sixteen new right-handed subjects participated in this experiment.

Materials. Line stimuli were identical to those in Experiment 3A, except that there were two squares on every card 1 cm (1.6°) beyond the left or right endpoint. For each of the three intersect locations (left, middle, right) four cards were constructed. On one of these both squares were empty; on another both contained dots. The remaining two cards had a dot in either the right or the left square. Thus on two of the cards the right square contained a dot and on two cards the right square was empty. The same was true for the left square. In addition, six cards were made with intersected lines only and no squares, two for each of the three intersect positions.

Procedure. There were four conditions of 48 trials each. The first condition was the "no square" or NO-SQ condition, in which only the intersect location was identified. The second was the "ignore squares" or IG-SQ condition, in which squares flanked the lines and the intersect location was identified while the squares were ignored. In the final two conditions, subjects attended to either the right (A-R) or the left (A-L) square, reported whether it contained a dot, and then identified the intersect location. Conditions were blocked so that subjects attended to the right or left square for a series of 48 trials. Order of the attend conditions was counterbalanced between subjects. Eight practice trials preceded each condition. To encourage central fixation, the number identification control was again used.

Exposure duration. Exposure duration was adjusted as in previous experiments. The average exposure duration was 39 msec for the IG-SQ and NO-SQ conditions and 70 msec for the A-L and A-R conditions (range 10–130 msec).

Results

A two-way ANOVA was used to analyze the shift scores across each of the four conditions. This revealed a main effect for condition, $F(3, 45) = 15.31$, $p < .001$, indicating that overall error rates, as reflected in the average shift scores, were significantly lower in the NO-SQ and IG-SQ conditions relative to both the A-R and A-L conditions. The difference in error rate between NO-SQ and IG-SQ just missed significance, $t(15) = 1.55$, $p < .08$. There was no overall difference in error rate between A-R and A-L.

The interaction of shift and condition was also significant $F(3, 45) = 3.81$, $p < .016$. Paired comparisons indicate no differences between LS and RS for the NO-SQ and IG-SQ conditions, reflecting the absence of attentional biases. There was also no difference between LS and RS in the A-L condition, indicating no consistent bias in bisection when subjects attended to the LVF square. Only the A-R condition was associated with a significant difference between LS and RS, indicating a striking rightward bias, $t(15) = 4.05$, $p < .05$, (see Table 7).

Discussion

The effect of greatest interest was the difference in bias produced by the instruction to attend to the right versus left square. In both conditions subjects were equally successful at detecting the target. The RVF detection task created a bias in the allocation of attention to a foveal line stimulus. However, there was no consistent bias when the target was in the LVF.

We know from Experiment 3A that the unilateral detection task is capable of eliciting both left and right biases. The detection task in the present experiment was the same except for the presence of bilateral squares. In the A-R condition line bisection performance closely resembled that found in Experiments 3A through 4 when only a RVF square was presented. Subjects performed as if there was no LVF square. In the A-L condition there was no overall bias. In contrast to the strong leftward bias found in Experiments 3A and 3B, and the moderate left bias in Experiment 4, the leftward orienting tendency was not expressed when the right square was present.

TABLE 7
MEAN SHIFT SCORES FOR EXPERIMENT 5

	Shift direction	
Viewing condition	Left (LS)	Right (RS)
No squares		
M	.06	.04
SD	(.04)	(.03)
Ignore both		
M	.08	.09
SD	(.07)	(.06)
Attend left		
M	.14	.14
SD	(.13)	(.11)
Attend right		
M	.07	.20
SD	(.07)	(.12)

Note. Shift scores are expressed in proportions formed by dividing the number of left shift or right shift errors in a given condition by the number of trials for that condition.

GENERAL DISCUSSION

The results of the present investigation are consistent with the activation-orienting hypothesis. Activation asymmetry produced by lateralized sensory input was associated with a contralateral bias in the spatial distribution of attention. Under conditions of predictable lateralized visual stimulation without conflicting orienting demands, both hemispheres demonstrate contralateral attentional biases which are opposite in direction but equivalent in magnitude. In the presence of orienting conflict due to location uncertainty or competing stimulation, the LH's bias was found to be more prominent than that of the RH.

Attentional Basis for Effects

There are two main points which argue in favor of an attentional basis for the lateral biases found in the present experiments. First, the results cannot readily be explained by nonattentional factors. In Experiment 1 the horizontal line was placed in the peripheral visual field toward the edge of the stimulus display. Because they were closer to the fovea, the inner segments of each line were associated with greater acuity and larger visual angle. Despite these factors, the inner segments were underestimated.

In Experiment 2 all lines were placed in the center of the stimulus display thus eliminating any effects from variations in the egocentric and spatiotopic position of the stimulus that may have been present in the first experiment. With these factors controlled the same pattern of results emerged.

In Experiments 3A through 4 the contribution of sensory interactions, such as lateral masking (Bouma, 1978), is also unlikely. The inhibitory influence of masking would have affected the region of the line adjacent to the square. Thus, the region closer to the square should have been underestimated when in fact it was overestimated.

The second argument for an attentional basis derives from considering the effect of instructions on line bisection performance. In Experiments 3A and 3B, a lateral stimulus which subjects were instructed to ignore produced a pattern of bisection errors strikingly similar to that found when subjects attended to the stimulus. Since attention shifts can be voluntary or involuntary (e.g., Jonides, 1980), it can be argued that the results in these two conditions have a common basis. The modes of control may differ, but a bias in the spatial distribution of attention underlies performance in both conditions. Furthermore, in Experiments 4 and 5, instructing subjects to attend to either the right or the left systematically biased perception of the horizontal line.

Hemispheric Activation and Attentional Orienting

Recent research has indicated that rather than being determined by hemispatial or egocentric coordinates, neglect phenomena associated with unilateral brain lesions may be object-centered and direction-specific. Thus the relative rather than the absolute location of events determines the occurrence of neglect. Patients with right parietal damage may ignore the left part of an object even in the RVF or right hemispace (Gainotti, D'Erme, Monteleone, & Silveri, 1986; Kinsbourne, 1970a). When two signals are presented in the RVF, right parietal patients respond more slowly to the leftward stimulus (Ladavas, 1987) and they show impaired attentional orienting in either visual field when the required shift is in the contralesional direction (Posner, Walker, Friedrich and Rafal, 1987).

The biases observed in the present study have similar properties. Experiment 2 indicated that the direction of the attentional bias was independent of the position of the stimulus with respect to the body midline but varied with the retinotopic location of the activating stimulus. Furthermore, rather than being distributed equally over the line, attention was displaced contralaterally. For example, LH activation biased attention to right side of the line in the RVF.

The similarity between the biases observed in the present study and those seen in neglect lends support to the idea that the biases have a common mechanism: activation imbalance produced by lesion or sensory stimulation determines the directional vector that will exert the predominant control on attentional orienting (Kinsbourne, 1987).

It was noted in the introduction that, in the cognitive task approach to the activation-orienting hypothesis, one hemisphere or the other may be activated during different stages of the task. A further concern, that is also relevant to the present method, pertains to which areas within a hemisphere become activated by a task or lateralized stimulus. Activation of some regions may assume more robust control of orienting than activation of others. Since the parieto-occipital regions and frontal eye fields are particularly important to spatial attention (see Robinson & Petersen, 1986 for review), activation asymmetries affecting these regions should influence orienting more so than activation of other areas. Thus the ability of different sensory modalities or cognitive tasks to modulate attentional orienting may depend in part on the extent to which particular regions within a hemisphere become activated during processing.

Hemispheric Differences in Attentional Control

The verbal response mode was used in every experiment in this investigation, including those in which no biases emerged (i.e., the baseline conditions of Experiments 4 and 5) and those in which the right and left biases were equivalent in magnitude (Experiments 1 and 2). Therefore it seems unlikely that the stronger rightward bias observed in Experiments 3B–5 was due to the use of a verbal response. The conditions that showed attentional asymmetries differed from those that did not only with respect to their visual and attentional demands. Therefore, it is with respect to these manipulations that we have interpreted the observed asymmetries.

The asymmetrical incidence of unilateral neglect has led to the hypothesis that the RH is dominant for attention (Heilman, Watson, & Valenstein, 1985; Heilman & Van Den Abell, 1979, 1980; Mesulam, 1981). According to this view, dominance involves the ability of the RH to attend to both sides of space whereas the LH attends to the right side only. The present findings point to an alternative way to think about the notion of attentional dominance by suggesting that differential lateral orienting strength may underlie the relevant behavioral asymmetries.

The final three experiments indicate that the attentional bias due to activation of the LH is more robust than the opposite bias that resulted from RH activation. The results suggest that differential orienting strength may have general consequences for the spatial distribution of attention. A closer examination of the notion of orienting strength will help to elucidate this issue.

There are two characteristics that may be associated with orienting strength: forcefulness and selectivity. The first may be most aptly depicted by the game tug-of-war, with its directional, motoric competition, in which the force of one opponent overcomes the force of the other. If the pull of the LH is stronger than that of the RH, rightward orienting would prevail. It is this ''relative force'' aspect of orienting which has been emphasized by Kinsbourne.

Spatial orienting serves as a selective device, giving information at the selected location a processing advantage over other nonselected locations. Therefore stronger orienting may also be associated with greater spatial selectivity or the relative narrowing of the region in space over which attention is distributed.

Both characteristics are evident in the present findings. Experiments 3B through 5 reveal that the RH bias is weaker, less forceful than the LH bias. In Experiment 5 the forcefulness of the LH's bias continues to manifest itself even in the presence of concurrent LVF stimulation. In this experiment a consequence of the weaker RH bias comes to the fore: the right and left line segments are attended to equally.

Forcefulness of orienting may work hand in hand with spatial selectivity. The greater orienting strength of the LH may induce greater spatial selectivity. Accordingly, if orienting is weaker under RH control, processing may be less spatially selective leading to greater readiness to receive and process input from diverse spatial locations. It has been proposed that the RH attentional mode is broadly receptive, involving ambient coverage of the perceptual array whereas the LH attentional mode is focal, dealing selectively with a restricted range of events (e.g., Kinsbourne, 1974b; Tucker & Williamson, 1984; see also Robertson, Lamb, & Knight, 1988). The claim that the RH attends bilaterally can also imply diffuse attention. The present results emphasize the idea that hemispheric differences in information selection and attentional allocation may be related to differences in orienting strength.

As in the clinical phenomenon of unilateral neglect, normal subjects showed a stronger rightward bias, resulting in a greater tendency for left than for right neglect. The findings support Kinsbourne's proposal that a stronger right orienting bias is a significant factor in the asymmetrical occurrence of neglect. Disinhibition of the LH following RH damage leaves the strong rightward orienting tendency of the LH unopposed and results in left neglect. The leftward bias of the RH that may predominate after LH damage is inherently weaker, leading to a directional bias of lesser severity.

Differential orienting strength may also underlie the RVF advantage reported in some luminance detection tasks which have used RT as an index of processing efficiency.[5] In some cases when cues of varying validity have been used to direct attention to the location of the subsequent target a RVF advantage has emerged (Egly & Homa, 1984; Hughes & Zimba, 1985; Gawryszewski, Riggio, Rizzolatti, & Umilta, 1987). Furthermore, a RVF advantage has been reported for choice RT tasks in which subjects must decide which of two targets appeared (Anzola, Bertolini, Buchtel, & Rizzolatti, 1977; Dee & Van Allen, 1973; Umilta & Nicoletti, 1985). Umilta and Nicoletti note that the RVF advantage occurred when the visual field of stimulation was randomized rather than blocked. This argues that the requirement of choice responding alone cannot account for greater LH involvement since the response requirements were the same in the blocked and random trials, but only the latter produced a RVF advantage.

In general it seems that when orienting is varied on a trial by trial basis or when stimulus location is random and discrimination between stimulus alternatives is required, there is greater likelihood that a RVF-LH advantage will emerge. On the basis of the present investigation this could reflect the stronger, more selective, orienting capabilities of the LH.

There are many different components of attention. While the present proposal does not rule out the possibility that the RH plays a greater

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[5] Simple RT tasks designed to examine compatibility effects have yielded faster detection for LVF than for RVF stimulus presentations (Anzola et al., 1977; Bradshaw & Perriment, 1970; Jeeves & Dixon, 1970). However, it is not clear that spatial attention influenced performance on these tasks. Simple RT may be influenced by the alerting effects of the command signal and there is some indication that the RH plays a greater role in this component of attention (Howes & Boller, 1975; DeRenzi & Faglioni, 1965. The LVF advantage that emerges under conditions in which neither discriminative orienting nor discriminative responding is required may reflect greater RH involvement in arousal.

role than the LH in some of them, it does call into question the claim that neglect can be interpreted simply as evidence of RH attentional dominance. The activation-orienting hypothesis offers a viable account of the dynamic interactions between lateralized control centers that govern the spatial distribution of attention. The present findings indicate hemispheric differences in the control of spatial attention and in so doing suggest that each hemisphere may play a specialized role in the attentional modulation of visual perception.

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