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Visual laterality effects: A signal detection analysis

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Subjects were asked to indicate, by a simple motor response, the presence or absence of a predesignated target letter in unilaterally presented consonant trigrams. For horizontally oriented stimuli (Experiment 1), perceptual sensitivity was greater in the right visual hemifield. For vertically oriented stimuli (Experiment 2), perceptual sensitivity did not differ between visual hemifields. Decision making was less conservative and reaction time was shorter with right hemifield presentation, regardless of stimulus orientation. Practice effects and serial position curves were examined. Implications of these results attribute laterality effects to iconic scanning patterns and to postperceptual decision processes.

When multiple-element, horizontally oriented, alphabetic displays are unilaterally presented, those placed in the right visual hemifield (RHF) are responded to more accurately and more quickly than those placed in the left visual hemifield (LHF). Both structural (Kimura, 1966; McKeever & Huling, 1971) and strategic (Heron, 1957; Kinsbourne, 1970; White, 1969) explanations have been proposed to account for these hemifield asymmetries in vision. Structural views generally predict an invariant superiority for language-related material when it is presented in the RHF, since this information is projected directly to the cerebral hemisphere primarily responsible for language function in most adults. Strategic interpretations of hemifield asymmetries, on the other hand, predict a more variable pattern of results, depending upon whether certain kinds of processing strategies are engaged by virtue of the material and task chosen. For example, hypothesized left-to-right scanning patterns of organizing visually presented material (Heron, 1957) lead to an advantage for RHF presentation only if these patterns are well established (Forgays, 1953; Miller & Turner, 1973). Investigators have also sought to control the contributions of scanning patterns by orienting stimulus displays vertically, under the assumption that these patterns were acquired during reading and hence are relevant only to horizontally oriented arrays. RHF advantages in recognition have been found for three-letter words (Barton, Goodglass, & Shai, 1965; Goodglass & Barton, 1963), four-letter words (McKeever & Gill, 1972), and four-letter approximations to English (Bryden, 1970). Discussions of the results in these "vertical" experiments have all centered on a (structural) cerebral dominance explanation of laterality effects.

The present research was designed to examine several characteristics of the orientation manipulation in more detail. Common to these "vertical" studies has been the nature of the subject's task: vocal recognition. A major problem with vocal response is that response determinants are confounded with analysis determinants. White (1972) has suggested that the superior RHF recognition of language stimuli may reflect the left hemisphere's ability to initiate vocal motor responses more than its ability to analyze language stimuli. For example, Bradshaw and Gates (1978) have demonstrated a stronger RHF advantage for overt naming than for lexical decisions with manual responses. This may again implicate a structural contribution to hemifield asymmetries, since response processes are also clearly lateralized. However, it remains unclear whether the appearance of an RHF advantage with vertical presentation reflects general facilitation effects associated with the response rather than factors associated with the encoding of information. If an RHF superiority with vertical presentation is due to such response effects, it should be absent with a manual response. A nonverbal response was consequently used to provide information relevant to this alternative.

Response effects of a somewhat different kind are suggested by recent signal detection analyses of hemifield differences in perception. Decision criteria differences between the visual hemifields have been observed (Gardner & Branski, 1976; Robertshaw & Sheldon, 1976; Shefsky, 1981). Such differences may contribute to an RHF advantage with vertical presentation of material. In addition to specific scanning strategies associated with reading, for example, there may be a more general perceptual set for different kinds of material to appear to the right of fixation (Rayner, 1978). If this is expressed as a response as well as a sensitivity difference, in terms of signal detection theory, reported accuracy differences for vertically oriented material are indeterminate. They may reflect higher (more cautious) criterion placement for LHF stimuli than for RHF stimuli, as well as differ-

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ences in sensitivity. Higher criterion placement for a hemifield ought to yield higher thresholds, lower hit rates, and correspondingly lower false alarm rates.

In the present research, signal detection theory (Swets, Tanner, & Birdsall, 1961) was applied to a task requiring target detection in consonant trigrams. This task was seen as relevant to potential strategic and structural models of perceptual asymmetry, since it required examination of more than one item in an alphanumeric array while requiring only minimal rehearsal or storage of encoded material (Smith & Ramunas, 1971). Subjects were asked to indicate, by a simple motor response, the presence or absence of a predesignated target letter in unilaterally presented consonant trigrams. The stimuli were vertically oriented for one group of subjects and horizontally oriented for another group. Models of asymmetry that hypothesize structural differences between hemispheres predict RHF advantages in detection accuracy, regardless of stimulus orientation. Models that attribute such asymmetries to perceptual scanning strategies suggest that hemifield differences in accuracy will be absent with vertical orientation. Finally, if the primary effect is upon decision processes, then asymmetries in response bias should be present.

All subjects were tested on 4 separate days in order to assess the stability of obtained measures. Practice effects have been given relatively little attention in studies of perceptual asymmetry, although it is not unreasonable to expect that various perceptual sets attributed to processing preferences of either hemisphere (Hellige, 1978; Kinsbourne, 1970) might change over trials. An assumption of manipulating orientation is that at least certain types of highly practiced encoding strategies are eliminated, presumably resulting in a relatively unfamiliar and more difficult task. Under such conditions, advantages for RHF material may also change. An increasing RHF advantage over trials for letter identification was observed by Hellige (1976) and was attributed to changes in the importance of visual encoding vs. phonemic access as the task became easier. This suggests that continued practice with vertically oriented stimuli would result in increases in perceptual asymmetry to the extent that such practice made the task easier. Such an interpretation does not appear appropriate to the results of Miller and Butler (1980), who found practice effects generally unrelated to task difficulty. Neither of these studies used signal detection procedures; consequently, the issue was investigated further here.

EXPERIMENT 1

Method

Subjects. Fourteen undergraduate students, eight male and six female, served as subjects. Only right-handed subjects were tested. All subjects had 20/30 Snellen acuity, or better, in each eye.

Stimuli. Each stimulus card contained a three-consonant sequence either to the left or to the right of the center of the card. All consonants, as well as the fixation "X," were Zipatone 18-point Franklin Gothic capital letters. Stimulus sequences were oriented horizontally. The distance from the center of a card to the inside edge of a three-consonant sequence subtended a horizontal visual angle of 42 min. The distance from the center of a card to the outside edge of a sequence subtended a horizontal visual angle of 1 deg 33 min. The vertical visual angle subtended by the letters was 17 min.

In all, 8 practice cards and 144 experimental cards were prepared; half contained the three-consonant sequence to the left of center (LHF cards), and half contained the sequence to the right of center (RHF cards). The set of cards for a visual field contained equal numbers of noise and signal cards. The particular consonants used for noise cards and their position in the sequence were chosen randomly. The signal cards were prepared such that the target letter appeared equally often in each of the three possible letter positions. The remaining two consonants on a card, and their order in the sequence, were chosen randomly. The consonant "W" was chosen as the target letter in order to minimize auditory and visual confusability of the target letter with other consonants. The particular consonant sequences employed were identical for each visual hemifield.

The 144 experimental cards were divided into four blocks of 36 cards each. Each block contained 9 LHF signal cards, 9 LHF noise cards, 9 RHF signal cards, and 9 RHF noise cards. The particular cards chosen for, and the order of the cards within, each block were selected randomly from the available cards.

The fixation X, located in the center of a card and at the same vertical level as the consonant sequences, resided in a separate field of the tachistoscope. The fixation X was constantly projected, except during stimulus exposure. The stimulus exposure duration was 4 msec. Pilot information suggested that such a duration would produce tolerable hit rates. The luminance of the fixation field, as well as that of the stimulus field, was 19 fL. Stimuli were shown in an Iconix tachistoscope modified to permit recording of response latency.

Procedure. Each subject was tested individually. Subjects controlled stimulus onset with the index finger of one hand and responded with the index and third fingers of the other hand. The experimenter gave a verbal "ready" signal before every trial. Upon hearing this signal, the subject was instructed to fixate the X and to press the start button with the index finger of the appropriate hand when ready. The subject was informed that during each trial, the X would be replaced briefly by a three-consonant sequence appearing either to the left or right of center. The subject was informed that: (1) the letter "W" was the target letter throughout the entire experiment and would be present on half the trials; (2) the task on each trial was to decide whether or not the target letter had been presented anywhere in the sequence; and (3) the decision need not be based on a clear visual image of the sequence, but rather, the subject should base the decision on whether he thought the target letter had been presented. The subject was instructed to be accurate and to make the decision as quickly as possible consistent with accuracy. A 30-sec break was given after every nine trials, and a 60-sec break was given at the end of each block.

Particular buttonpresses for "yes" and "no" responses were counterbalanced across subjects. For half of the subjects, a "yes" response consisted of an index finger buttonpress and then a third finger buttonpress, while a "no" response consisted only of an index finger press. For the other subjects, buttonpressing procedures were reversed (i.e., index finger for "yes," index and third fingers for "no"). The nature of a press for "yes" or "no" was kept constant for each subject throughout testing.

Each subject was tested on 4 separate days. On Day 1, 8 practice trials and 144 experimental trials (four blocks of 36 cards each) were presented. Within a subject, the hand of response across blocks was counterbalanced in ABBA fashion. Across subjects, the initial hand of response was counterbalanced. The procedure for Days 2, 3, and 4 was identical to that for Day 1, except that, for a given subject, the initial hand of response on a day was counterbalanced in ABBA fashion. The same 8 practice cards and 144 experimental cards were used on each day of testing.

Results

Data for all practice trials have been excluded from all analyses that follow. Each of 14 subjects was tested with 288 experimental trials in each visual hemifield over 4 days of testing. Three dependent measures were computed for each subject by hemifield: d′, β, and mean reaction time (for correct positives). Table 1 shows the means of hit rate, false alarm rate, d′, and reaction time for each hemifield of stimulus presentation. Given the characteristics of the β scale, a logarithmic transformation was performed prior to statistical computations. Also shown in Table 1 are mean log β and antilog (mean log β) for each hemifield.

Matched-pairs t tests were performed to determine the effect of hemifield of stimulus presentation. The hemifield effect on d′ was statistically significant [$t(13) = 5.37$, $p < .001$, one-tailed]. Perceptual sensitivity was greater for RHF than for LHF presentation. The hemifield effect on log β was statistically significant [$t(13) = 2.94$, $p < .01$, one-tailed]. Decision making was more conservative (i.e., criteria were placed higher) for LHF than for RHF presentation. The hemifield effect on reaction time was statistically significant [$t(13) = 3.69$, $p < .005$, one-tailed]. Reaction times were higher for LHF than for RHF presentation.

Examination of individual patterns of performance indicated these summary statistics were representative of almost all subjects. With respect to d′, 13 subjects showed an RHF advantage, while one subject showed an LHF advantage. With respect to β, 12 subjects showed higher scores for stimuli in the LHF than for those in the right, while two subjects showed the opposite. With respect to reaction times, 13 subjects showed an RHF advantage, while one subject showed an LHF advantage.

Figure 1 displays d′ for each half of the experiment. The size of the laterality effect on d′ increased over testing. In order to test the statistical significance

Table 1
Means Across Subjects (n = 14) With Horizontally Oriented Stimuli: Hit Rate (in Percent), False Alarm Rate (in Percent), d′, Reaction Time (in Milliseconds), and Log β

	Right Hemifield		Left Hemifield	
	Mean	SD	Mean	SD
Hit Rate	82		67	
False Alarm Rate	19		19	
d′	1.89	.58	1.41	.52
Reaction Time	605	103	640	116
Log β	.0222	.2292	.1756	.1620
Antilog (Mean Log β)	1.05		1.50	

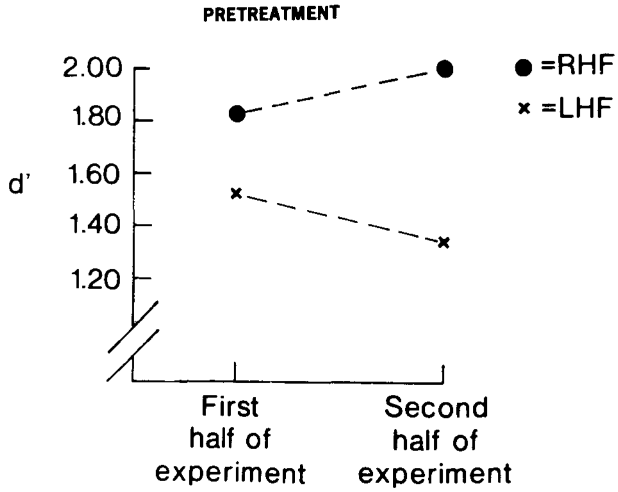

Figure 1. Mean d′ (n = 14), with horizontally oriented stimuli, at each half of the experiment.

of the increased RHF advantage, the hemifield differential (i.e., d′ in the RHF minus d′ in the LHF) was computed for each subject at each half of the experiment. A matched-pairs t test revealed that this effect was statistically significant [$t(13) = 3.44$, $p < .005$, one-tailed]. The size of the hemifield differential was larger for the second half of the experiment than for the first half.

The reader will recall that the target letter appeared equally often in each possible letter position. If normal reading habits are employed as a strategy for scanning the iconic image, then one would expect reaction times for correct detections to be lowest for the leftmost position of the display and to increase moving to the middle and rightmost positions. Likewise, percent correct detection should decrease moving from the left- to the rightmost display element. Examination of the data by target position indicated that for both RHF and LHF stimuli, percent correct detection was highest for the leftmost element in a display. Also, for both RHF and LHF stimuli, reaction time for correct positives was lowest for the leftmost element in a display and increased for the middle and rightmost positions.

Discussion

Consistent with expectations, laterality effects were demonstrated in the present letter detection task for both sensitivity and criterion measures of performance. Comparable signal detection measures for unilateral presentation have been provided by Shefsky (1981) and Shefsky, Stenson, and Miller (1980). Sensitivity was greater and decision making was less conservative in the RHF than in the LHF. The hemifield effect on d′ may be due, in part, to structural differences in sensitivity or to strategic (scanning) factors. The response bias may be understood in terms of acquired reading habits. The presence of potential target information to the right of fixation during reading may make observers more ready to identify language material to the right as containing targets. Alternatively, cerebral asymmetries in attention, such as those described by Kinsbourne (1970), may be expressed by criterion effects (Gardner & Branski, 1976).

The effect of task familiarity also operated differently in each visual hemifield. Detection accuracy in the RHF increased over testing, while accuracy in the LHF decreased, resulting in an increased laterality effect over days. This effect is consistent with Kinsbourne's (1970) cerebral activation hypothesis. Accordingly, the expectations of the letter detection task activate the left cerebral hemisphere, inhibit the right hemisphere, and bias attention toward the RHF. Although an attractive explanation, Kinsbourne's model is not the only possible reason for an increasing RHF advantage. Subjects may attempt to optimize overall performance at the expense of LHF stimuli. The LHF may be ignored because it is easier to process (scan) RHF stimuli due to left-to-right scanning habits beginning at the fixation point.

Examination of the serial position effects suggests sequential, left-to-right processing of trigrams, regardless of the hemifield of presentation. These data are in accord with a postexposural scanning hypothesis of visual asymmetry. Furthermore, these data reveal the absence of a speed/accuracy tradeoff. Such a tradeoff would predict that quick responses would be associated with low accuracy. This effect, however, was not obtained in the present study. Rather, quick responses were associated with high accuracy.

If, indeed, mechanisms from both models (i.e., unilateral cerebral activation and postexposural scanning) are operating, then it might be possible to assess the relative contribution of each to the hemifield effect. For instance, vertically oriented trigrams would eliminate the differential scanning patterns between the hemifields. Laterality differences that remain reflect structural differences in processing efficiency and associated biases in cerebral activation.

EXPERIMENT 2

Method

Subjects. Thirteen undergraduate students, five male and eight female, served as subjects. Only right-handed subjects were tested. All subjects had 20/30 Snellen acuity, or better, in each eye.

Stimuli. Each stimulus card contained a three-consonant sequence either to the left or to the right of the center of the card. Stimulus sequences were oriented vertically. Fifty-nine minutes of arc separated the fixation X from the center of the middle letter of the display. The three-consonant display subtended a vertical visual angle of 51 min. (The center element in these vertical stimuli was located exactly in the position of the center element of the horizontal stimuli of Experiment 1.) Stimulus preparation was identical to the procedures outlined in Experiment 1: The same trigrams were used.

Procedure. All procedures were identical to the procedures outlined in Experiment 1.

Table 2
Means Across Subjects (n = 13) With Vertically Oriented Stimuli: Hit Rate (in Percent), False Alarm Rate (in Percent), d′, Reaction Time (in Milliseconds), and Log β

	Right Hemifield		Left Hemifield	
	Mean	SD	Mean	SD
Hit Rate	86		78	
False Alarm Rate	22		15	
d′	2.03	.63	1.94	.70
Reaction Time	629	82	648	91
Log β	−.2004	.3190	.1149	.2206
Antilog (Mean Log β)	.63		1.30	

Results

Data were analyzed in the same manner as in Experiment 1. Table 2 shows the means (n = 13) of hit rate, false alarm rate, d′, and reaction time for each hemifield of stimulus presentation. Also shown in Table 2 are mean log β and antilog (mean log β) for each hemifield.

Matched-pairs t tests were performed to determine the effect of hemifield of stimulus presentation. The hemifield effect on d′ was not statistically significant [$t(12) = .88$]. The hemifield effect on log β was statistically significant [$t(12) = 3.99$, $p < .001$, one-tailed]. Decision making was more conservative (i.e., criteria were placed higher) for LHF than for RHF presentation. The hemifield effect on reaction time was statistically significant [$t(12) = 2.47$, $p < .025$, one-tailed]. Reaction times were higher for LHF than for RHF presentation.

With respect to d′, nine subjects showed an RHF advantage, while four subjects showed an LHF advantage. With respect to β, 12 subjects showed higher scores for stimuli in the LHF than for those in the right, while one subject showed the opposite. With respect to reaction times, nine subjects showed an RHF advantage, while four subjects showed an LHF advantage.

Figure 2 displays d′ for each half of the experi-

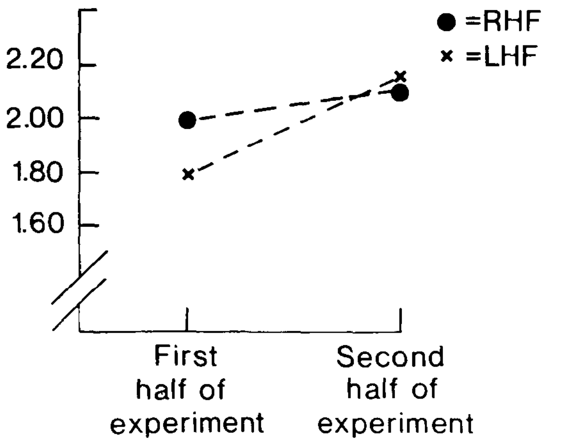

Figure 2. Mean d′ (n = 13), with vertically oriented stimuli, at each half of the experiment.

ment. The size of the laterality effect on d′ decreased over testing. In fact, for the last half of the experiment, a slight LHF advantage was obtained. In order to test the statistical significance of the decreased RHF advantage, the hemifield differential (i.e., d′ in the RHF minus d′ in the LHF) was computed for each subject at each half of the experiment. A matched-pairs t test revealed that this effect was only marginally significant [$t(12) = 1.91$, $p < .10$, two-tailed].

In order to assess postexposural scanning factors, serial position of the target was again examined. For both RHF and LHF stimuli, percent correct detection was highest for the topmost element in a display. Also, for both RHF and LHF stimuli, reaction time for correct positives was lowest for the topmost element in a display and increased for the middle and bottommost positions.

Discussion

Perceptual sensitivity, as measured by d′, was statistically no better in the RHF than in the LHF. With the effect of differential scanning minimized by the use of vertical displays, the effect of vocal response eliminated, and the effect of response bias teased out, there remains no perceptual laterality effect. If one ignores the statistical significance tests and visually examines both the detection measures and reaction times in Table 2, it is possible that a small effect due to structural differences between the cerebral hemispheres is present. However, the differences are minute if they are indeed robust. The vast majority of the variance seems to be accounted for by the switch from horizontal to vertical stimuli. In the horizontal displays (Experiment 1), the RHF advantage appears to be due to postexposural scanning strategies. The subjects appeared to scan from left-to-right. Thus, minimal scanning time was lost for RHF stimuli as the scan progressed from fixation. The LHF stimuli were at a disadvantage—a left-to-right scan here involved a leftmost element three positions away from fixation. For the vertical displays, no differences in scanning pattern were evident, and hemifield differences all but disappeared.

As in Experiment 1, decision making was less conservative in the RHF than in the LHF. The hemifield effect on β originates postperceptually. Decision making, obviously, must operate after stimulus encoding (into short-term memory). The hemifield effect on reaction time, also, originates postperceptually. That is, if it took longer to encode LHF stimuli, then less information would arrive at short-term memory (given the nature of the rapidly fading icon) and would thus produce perceptual sensitivity differences between hemifields. This latter effect, however, was not obtained. Thus, differences in reaction time need not, necessarily, indicate differences in encoding speed or efficiency. The present results suggest biases beyond those reflecting differences in the quality of information in short-term memory.

The present results question previous conclusions that perceptual asymmetries are found even under conditions designed to eliminate scanning or strategic effects in visual half-field identification. Asymmetries remain, but they may not reflect differences associated with structurally bound encoding skills. Furthermore, the different patterns of results found for d′, β, and reaction time suggest that these reflect somewhat different aspects of the perceptual process.

Finally, the differences found between Experiments 1 and 2 for the effect of practice are striking. Whatever may be the cause of the asymmetry in detection for horizontal displays, the effect increases with practice (Figure 1). For vertical displays, the effect is eliminated with practice (Figure 2). This finding has implications for all experiments on laterality and suggests that experimental findings may depend heavily on the number of trials on which they are based or the amount of practice given prior to the experimental trials.

For future research, the findings here suggest that detection, scanning patterns, practice, and response biases all need to be studied simultaneously to assess the causes of perceptual performance asymmetries.

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