

Orienting Attention Within Visual Fields: How Efficient Is Interhemispheric Transfer?

Curtis Hardyck

Institute of Cognitive Studies, University
of California, Berkeley

Nina F. Dronkers

Institute of Cognitive Studies, University
of California, Berkeley

Christine Chiarello

Syracuse University

Gregory V. Simpson

Institute of Cognitive Studies, University
of California, Berkeley

Five experiments are reported examining the effect of attentional orienting on lexical decisions within visual half-fields. In Experiment 1, following baseline performance, subjects were instructed to improve performance to the right or left of the fixation point. In Experiment 2, trials were run in blocks with all items to one side of the fixation point. In Experiment 3, completely valid position indicators as to the location of the next item to be shown were presented prior to the stimulus item. In Experiment 4, to examine practice effects, no instructions or cuing were given to subjects. In Experiment 5, subjects were urged to improve performance, but with no instructions as to location. As a summary of our results, it can be stated that (a) consistent visual field differences in lexical decision performance are present, even when subjects were informed, prior to viewing, of the spatial location of the next stimulus item. (b) Lexical decision information initially input to one cerebral hemisphere is primarily processed in that hemisphere. Interhemispheric transfer of this type of language information seems to be done primarily as the end product of a cognitive process.

Under normal circumstances, when viewing objects or events in the world, we bring foveal vision to bear on whatever has attracted our attention, thus ensuring the presentation of identical information to both hemispheres of the brain. Usually, under these conditions foveal vision and the orienting of attention are coordinate.

When information is presented to only one visual half-field, as in a cerebral lateralization experiment, there is an abnormal situation in which visual fixation is on a defined point and attention must (usually) be directed to each side of that fixation point. A cooperative subject in such a setting has divided his or her attention to each side of a fixation point, knowing that information will randomly appear to either side. The assumption is made that the subject's attention is divided equally

to the areas right and left of the fixation point and that differences in performance between the visual fields reflect differential hemispheric processing. The basis of differential hemisphere processing is attributed to either (a) structural brain differences or (b) cortical processes not accessible to conscious manipulation.

An alternative explanation for performance differences between visual fields is the possibility that the subject has a tendency to attend more to one visual field. Presumably, such a bias in allocation of attention to one visual field could produce both greater accuracy of identification and faster reaction times for stimuli in that field. We can test these contrasting views of visual field performance by introducing experimental manipulations of attention. If a bias can be produced by instructing the subject to direct attention to a given visual field, an improvement in performance should occur in that visual field relative to performance with no attentional bias or a bias to the other visual field. Correspondingly, if no change in performance can be produced by directing attention, then attentional bias can

We would like to thank William Epstein, Martha Polson, and two anonymous reviewers for their helpful comments.

Requests for reprints should be sent to Curtis Hardyck, Institute of Cognitive Studies, University of California, Berkeley, California 94720.

be eliminated as a major contributor to observed differences in hemisphere performance.¹

This approach to inferences about hemispheric specialization was first proposed by Bryden (1980) in a critical commentary on tendencies to interpret observed cerebral lateralization differences as indicative of structural brain differences. Bryden argued that there were many alternative explanations that would account for observed differences just as well as structural brain differences and suggested that attentional bias, perhaps related to handedness, could account for many of the observed asymmetries reported.

As an illustration, Bryden reported a dichotic listening experiment in which digits reported under conditions where the subject was asked to "attend" more to one ear than the other were compared to conditions in which no localization instructions were given. He found that the attending instructions produced a substantial shift in reporting accuracy in favor of the attended ear.

It seems clear that an attentional bias hypothesis should be seriously considered, given the extensive series of studies on the ability to orient attention within the field of vision independently of eye movements (Eriksen & Hoffman, 1973; Klein, 1979; Posner, Nissen, & Ogden, 1978; Shaw, 1978; Van Voorhis & Hillyard, 1977). The basic findings about human ability to focus visual attention can be summarized as follows:

1. Attention can be oriented and focused within the subject's field of vision by means of instructions to the subject (Eriksen & Hoffman, 1973; Klein, 1979; Posner, Nissen, & Ogden, 1978; Shaw, 1978; Van Voorhis & Hillyard, 1977).
2. Attention appears to operate in an analog mode, in that attention is shifted much as one would move the beam of a searchlight rather than as a process where attention moves discontinuously from one area in the field of vision to another (Shulman, Remington, & McLean, 1979).
3. Attention seems to have a gradient of sensitivity surrounding the area of focus, in that awareness of sensory input increases with proximity to the area of attentional focus (Remington, 1980).

4. Attention seems strongly time linked, reaching an optimum focus approximately 300–400 ms after an orienting cue has been provided (Shulman, Remington, & McLean, 1979).

Given the thoroughness of the above series of studies, it would seem reasonable to assume that asymmetries in the orienting of attention might account for some of the visual asymmetries reported in the study of human cerebral lateralization. However, in making such an assumption, it should be kept in mind that the work summarized above was focused on the study of relatively simple sensory detection tasks such as a light flash or a change in brightness. Such tasks are not appropriate measures of cognitive processes showing lateralization differences, and it is unclear whether shifts in the spatial allocation of attention can alter performance when the task requires a cognitive decision. It should also be emphasized that Bryden (1980) investigated *auditory* attention shifting relative to observed cerebral asymmetries where the studies cited on *visual* attention shifting (Eriksen & Hoffman, 1973; Klein, 1979; Posner, Nissen, & Ogden, 1978; Van Voorhis & Hillyard, 1977) were not carried out relative to any observed lateralization differences.

The argument can be made that there is no direct basis for assuming that biasing of attention will facilitate performance on a demanding cognitive task. However, given Bryden's results, it is appropriate to show that such psychological factors do not play a major part in visual field differences before carrying out inferences about cerebral hemisphere specialization as the basis for differences in observed performance levels.

We report here the results of five experiments examining the ability of subjects to shift attention within visual fields while carrying out

¹ It should be noted that our use of attention and attentional bias is in accord with Posner's (1980) use of the term. Attentional bias in hemisphere function, as proposed by Kinsbourne (1975), is not postulated to be under the conscious control of the subject and is therefore not subject to experimental manipulation of the kind proposed here. Given the limited conditions under which the Kinsbourne model can account for hemisphere differences (cf. Hellige & Cox, 1976), we did not attempt to evaluate any such biasing mechanism not under the subject's control.

a complex language task. If visual asymmetries in the performance of complex tasks are in part a function of attentional biases (Bryden, 1980), then it should be possible to manipulate these biases experimentally. The experiments reported here are systematic attempts to alter visual field differences by biasing subjects' attention within visual fields. If differences in asymmetries found under conditions of random visual field presentation can be shifted through the biasing of attention, the concept of specialized hemisphere differences in cognitive functioning should be downgraded in importance. However, if visual field asymmetries remain constant despite such manipulations, we can place more confidence in interpretations of such asymmetries as reflecting specialized hemispheric processes. The results will also indicate whether shifts in the spatial allocation of attention can alter performance when a decision is required about the nature of the stimulus, rather than a simple detection response.

We wanted to examine a process that required the subject to perform some reasonably complex cognitive judgments that could be varied as to difficulty level and that would produce a range of performance. We selected lexical decisions (deciding whether a letter string is or is not an English word) as a suitable task. This task provides a measure of access to the internal lexicon (Coltheart, 1980). It has been employed by numerous investigators to examine hemispheric asymmetries for a language process that does not require vocal speech output (e.g., Barry, 1981; Bradshaw & Gates, 1978; Chiarello, Dronkers, & Hardyck, 1984; Leiber, 1976; Zaidel, 1983). Thus, our study will assess the manipulability of visual field asymmetries for a *receptive* language process, for which some right hemisphere mediation is plausible (Corballis, 1983).

A similar procedure was used in all experiments. Subjects viewed words with high ratings on imagery, concreteness, and familiarity. Nonwords were pronounceable and constructed in accord with English orthographic rules. Following a brief practice period, all subjects responded manually to a beginning set of 200 items presented randomly for 100 ms to the right and left of a central fixation point. This served as a baseline of performance on the lexical decision task. Eye position was

monitored by an eye-tracking apparatus linked to a computer controlling the stimulus display, ensuring that eye position remained steady. In Experiments 1 through 5, techniques for producing attentional bias were varied. The procedure used in Experiment 1 will be presented in detail. Changes in procedure for other experiments will be specified, but where not explicitly stated, procedures were identical to those described for the first experiment.

Experiment 1: Instructional Manipulation of Attention

In Experiment 1, 12 subjects completed the first block of 200 trials under conditions of random right-left presentation with a 100-ms exposure. At the beginning of the second block, the subject was specifically instructed to pay more attention to a given side and to try to improve accuracy for items appearing to that side of the fixation point. The importance of remaining fixated on the central marker was emphasized. When the second block was completed and the subject ready for the third block, he or she was then asked to try to improve accuracy in the field opposite the one previously instructed. This manipulation is analogous to that employed by Bryden (1980) in his auditory lateralization experiment.

Method

Subjects. Subjects were recruited from introductory psychology classes, being told at the time of recruitment that they would be paid for their participation. At this time, all potential subjects filled out a brief questionnaire asking about handedness, handedness of immediate relatives, the wearing of eyeglasses or contact lenses, and whether English was their first language. Persons who were left-handed or who had left-handed relatives and persons who lacked English as a first language did not participate. Sex of subject was equated for all experiments. Twelve subjects participated in Experiments 1, 2, 3, and 5. Six subjects participated in Experiment 4.

Materials. Stimulus items consisted of 150 five-letter words and an equivalent number of nonwords, presented horizontally in uppercase. We selected words from the norms published by Toggia and Battig (1978), which were rated high on the dimensions of imagery (5.71), concreteness (5.76), and familiarity (6.06). Nonwords were pronounceable five-letter strings, nonhomophonic to actual English words and constructed in accord with English orthographic rules. They are the maximally difficult stimuli possible without introducing phonological confusions with actual words. All stimuli were constructed with 24-point Helvetica letters, photographed with Kodak technical Pan film and mounted on 2 × 2 slides. The use of this film

allows a high-contrast light image against a black background. When projected, the inner edge of each item was located 2.25° of visual angle from a central fixation point. The items subtended 1.8° to 2.0° of horizontal visual angle. Illumination level of the room as measured at the display screen was 5.14 cd/m^2 between trials and 8.57 cd/m^2 during stimulus presentation.

Apparatus and procedure. Items were back-projected on a screen located 162 cm from the subject, using Kodak Ektagraphic self-focusing projectors with Uniblitz shutters having a rise and fall time of approximately 3 ms. A fixation point was provided by two special 3-v bulbs with focusing lenses producing a display similar in appearance to $><$ in the center of the screen. The subject sat in an armchair modified to hold a head-positioning device adapted from a Tektronix oscilloscope viewing hood. This served to fix head position while allowing the subject to speak. A remote eye-movement monitoring system (Gulf & Western 1994s) was located 38 cm from the subject. Responses were made by push-button switches held in each hand and activated with the thumb.

At the beginning of the session, subjects were asked to wear the glasses or contacts normally used for reading and were then tested for acuity on a Bausch & Lomb Orthorater. Subjects scoring less than 10 correct (equivalent to 20-20 vision) on the acuity test were paid for 1 hr but not used in the experiments. Following acuity testing, subjects were seated in the experimental room and the procedure explained. To begin, subjects fixated on the center of the screen, the eye movement monitor was aligned, and the digital X and Y coordinates of eye position for the fixation point $><$ were determined and supplied to a PDP-11 computer. Subjects were told that letter strings would appear randomly to each side of the fixation point for 100 ms, but would not appear if they were not focused on the central fixation point. When the item appeared, they were to press a designated switch if they thought the item to be a word, and the other if they thought it not to be a word.

Subjects were given 40 practice trials on items not included in the experimental set. Presentation of trials was controlled by a PDP-11 computer interfaced with the eye tracker. The digital coordinates taken at the time the eye monitor was aligned with the subject's central fixation were compared with the digital coordinates sampled by the eye monitor prior to exposure of the stimulus item. Eye position was sampled every 16.7 ms. Our procedure required five successive samples of eye position to be within $.25^\circ$ of visual angle of the X and Y central fixation coordinates before the test item was shown. This ensured that stimuli would not be shown in the course of a rapid scanning movement across the fixation point. When this criterion was satisfied at the onset of a trial, the fixation point disappeared as the letter string was shown for 100 ms. The average intertrial interval was 3-5 s between the response of the subject and the display of a new stimulus, but was longer if the subject was not fixating within the defined area because stimulus presentation was delayed until sampling of eye position indicated appropriate fixation. In addition to the computer sampling, the experimenter was able to observe the subject on three television monitors showing the subject's left pupil as monitored by the eye monitor, the head position of the subject, and the scene as viewed by the subject, complete with cross-hair display showing the fixation of the subject. When the subject responded, the fixation point reappeared, and examination

of eye position data was resumed prior to displaying the next item.

A total of 600 trials was run for each subject, trials being run in blocks of 200, after which the subject was given a brief rest and refreshment if he or she wished. Eye position calibration was carried out prior to each block of 200 trials.

As mentioned earlier, the total pool of items consisted of 150 words and 150 nonwords. Items were repeated once in the course of an experiment but were balanced so that no item ever reappeared in the same visual field. Slides used within a 200-trial block were varied, so that two orders of presentation of words and nonwords were used. Responding hands for word-nonword decisions were counterbalanced. Although accuracy was the primary dependent measure, reaction times in milliseconds were recorded from the end of the stimulus exposure until a response was made.

At the end of the experimental session, the results of each of the 200-trial blocks were shown to the subject and interpreted. Subjects then filled out a handedness questionnaire (Oldfield, 1971) and a family history of handedness inventory, as an additional check on information obtained at the time the subjects were recruited.

Results

Data were examined for each visual field for each block of 200 trials. Preliminary analyses ruled out any reliable effects attributable to stimulus order, responding hand, or sex of subject.

A repeated measures $2 \times 3 \times 2$ analysis of variance with main factors of decision type (words or nonwords), condition (baseline divided attention, orienting right, orienting left), and visual field was carried out on the proportions of correct identifications for words and nonwords.² Statistically significant effects were found for decision type and visual field, and for the interaction of decision and visual field. In Figure 1, results are shown averaged over all subjects for baseline and orienting conditions, with proportions of correct identifications of words and nonwords in the right and left visual fields.

Summary statistics reaching conventional significance levels for all analyses done on Experiments 1 through 5 can be found in Table 1.

Results can be summarized as follows: Correct identification of words in the right visual field leading to the left hemisphere (RVF-LH)

² The analyses reported here were performed on the proportions of correct decisions to words and nonwords. The same analyses were done using an arc-sine transformation, producing such minuscule changes in outcome statistics as to render the transformations unnecessary.

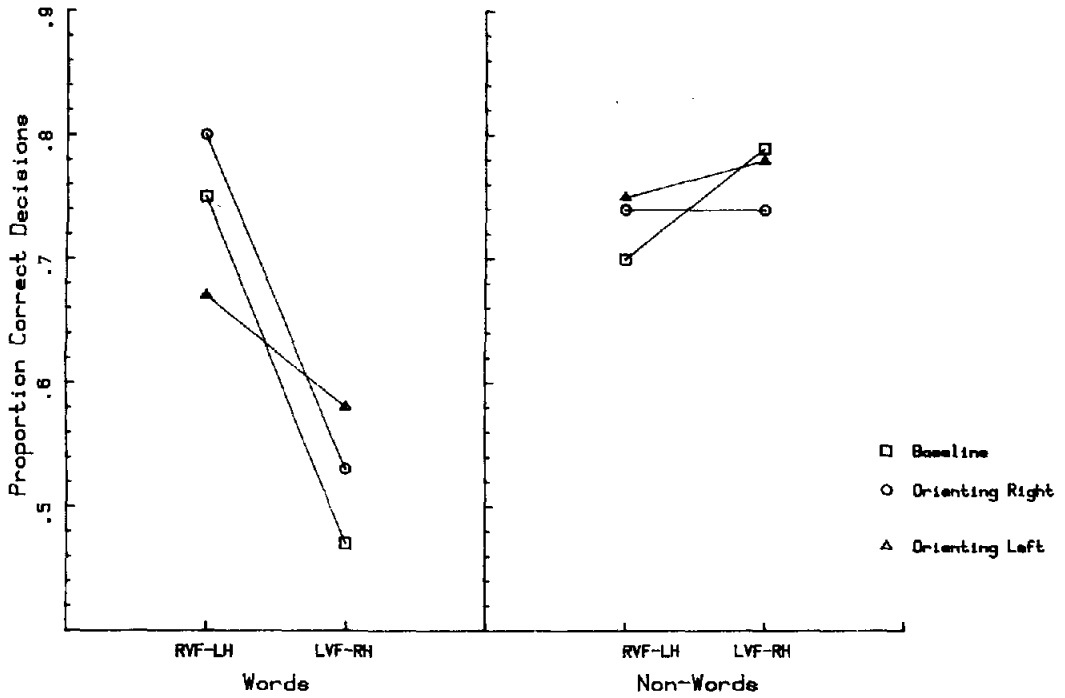


Figure 1. Experiment 1: Response accuracy within visual fields for baseline, orienting right instructions, and orienting left instruction conditions. (RVF = right visual field; LH = left hemisphere; LVF = left visual field; RH = right hemisphere.)

was quite high, in contrast to a relatively poor performance in the left visual field leading to the right hemisphere (LVF-RH). The correct identification of nonwords was uniformly high in both visual fields.

Inspection of Figure 1 suggests that our instructions regarding performance within visual

fields had quite different effects. Instructions to improve performance on the right produced no differential effect, the slight improvement in performance in the RVF being accompanied by an equal improvement in performance in the LVF. Instructions to improve performance in the LVF produced a much larger apparent

Table 1
Analysis of Variance Summary Statistics: Accuracy Measures, Experiments 1-5

Source of variance	1	2	3	4	5
Decision type (words-nonwords)					
df	1, 11	1, 11	1, 11		1, 11
F	13.73	5.75	4.68		19.96
ω^2	.13	.05	.03		.11
Visual field					
df	1, 11	1, 11	1, 11	1, 5	1, 11
F	8.41	13.08	9.14	22.55	16.71
ω^2	.08	.12	.07	.20	.11
Decision Type \times Visual Field					
df	1, 11	1, 11	1, 11	1, 5	1, 11
F	16.18	12.68	18.12	21.51	17.46
ω^2	.16	.12	.15	.18	.12

Note. All values cited at $p = .05$ or less.

Table 2
Analysis of Variance Summary Statistics: Reaction Times, Experiments 1-5

Source of variance	1	2	3	4	5
Decision type					
<i>df</i>	1, 11	1, 11	1, 11	1, 5	1, 11
<i>F</i>	8.97	32.53	78.80	41.00	28.18
ω^2	.03	.13	.24	.18	.12
Condition					
<i>df</i>	2, 22	1, 11	2, 22	2, 10	2, 22
<i>F</i>	47.88	110.86	45.46	53.49	33.85
ω^2	.38	.43	.28	.47	.29
Visual field					
<i>df</i>		1, 11	1, 11	1, 5	
<i>F</i>		23.74	15.32	14.34	
ω^2		.09	.05	.06	
Decision Type \times Visual Field					
<i>df</i>	1, 11	1, 11	1, 11		
<i>F</i>	15.29	7.16	7.91		
ω^2	.02	.03	.02		

increment of improvement, with a drop in performance in the RVF similar in magnitude to the LVF improvement.

However, results of an analysis of variance suggest the interpretation indicated by Figure 1 is more apparent than real, the interaction of condition with visual field being nonexistent $F(2, 22) = .91$. Thus, instructing our subjects to bias their attention in a given direction has no discernible effect on accuracy.

Significant main effects of decision type are clearly due to subjects' superior ability to identify nonwords present in both visual fields. The significant main effect of visual field is almost entirely due to the difference in word identification accuracy between the RVF and the LVF. The significant interaction of decision type and visual field reflects differential visual field accuracy of identifying words relative to nonwords, visual field accuracy being almost identical in the identification of nonwords.

Examination of reaction time data indicates that visual field accuracy is not dependent on a speed-accuracy trade-off. An analysis of variance on mean reaction times for correct decisions on words and nonwords revealed significant effects for decision type, condition, and the interaction of decision type with visual field. Subjects respond more quickly to words than to nonwords and show substantial improvement in response speed over trial blocks. The interaction of decision type with visual

field is accounted for by the faster response time to words in the RVF as compared to the LVF, in contrast to the lack of such visual field differences in response times to nonwords. The analysis of variance reaction time summary statistics for Experiments 1 through 5 are presented in Table 2. The mean of individual means for correct word identifications in the baseline divided-attention condition in the RVF is 955 ms and in the LVF, 1,125 ms. This difference remained constant under instructions to improve RVF performance, the mean of individual means being 715 ms for the RVF and 865 ms for the LVF. When instructed to improve performance in the left, the means of reaction times are virtually identical at 825 ms for the RVF and 823 ms for the LVF. Reaction time differences between visual fields in the correct identification of nonwords are quite small, with no significant visual field differences.

In view of the rather large differences in reaction time shifts for the conditions, a separate analysis of variance on reaction times for words only was carried out. In this analysis, significant effects were found for experimental condition (baseline, orient right, orient left), $F(2, 22) = 34.68$, $p < .001$; visual field, $F(1, 11) = 7.31$, $p < .02$; and the interaction of Condition \times Visual Field, $F(2, 22) = 6.76$, $p < .005$. A similar analysis on the accuracy data for words only produced a significant main effect

for visual field, $F(1, 11) = 37.06$, $p < .001$; no other comparisons even approached acceptable significance levels.

The differences in performance between the RVF and the LVF are in accord with the types of differences that have been reported in many experiments (For reviews, see Beaumont, 1982; Bradshaw & Nettleton, 1981; Hardyck, 1983) and are not especially surprising.

The most important aspect of the data is directly related to the attentional bias hypothesis and concerns what appears to be an inability to improve performance in a visual field relative to the other visual field by means of instructions. Even though the data displayed in Figure 1 give the impression that instructions to improve are slightly more effective in the LVF than in the RVF, the direct test of the attention shifting hypothesis—the interaction of condition and visual field—did not begin to reach an acceptable level of significance.³

Given the significant Condition \times Visual Field interaction found for reaction times, it is evident that our instructions had an effect on speed of response, if not accuracy. Although our subjects responded more quickly to a given visual field when instructed to improve performance, the level of accuracy did not change with respect to the decrease in response time. One possible interpretation of the reaction time results would suggest that attentional shifts play a relatively minor role in accounting for hemisphere differences in complex tasks such as lexical decisions. When attention must be divided between visual fields, there is a 170-ms advantage in reaction time to the RVF. When subjects are instructed to attend to the RVF, the advantage to the RVF is 150 ms, which, although less than the baseline advantage, still represents a substantial RVF advantage after practice. When subjects are instructed to attend to the LVF, there is a 2-ms advantage to the LVF, suggesting that, although attention shifting may be present, the maximum effect is to equalize the speed of response for the hemispheres, without providing any accuracy advantage. If attention shifting were to account for much of the observed hemisphere differences in performance, it seems reasonable to expect reaction time (and accuracy) differences to show more symmetrical shifts rather than have attentional bias bring the LVF to the RVF level of response time.

Because RVF accuracy performance is much better, the possibility exists that RVF performance was already at its maximum. However, if we wish to entertain this explanation, we are then faced with explaining why the LVF does not also work at a peak performance level. Before concluding that attention to spatial location is not effective in this type of task, it is necessary to carry out additional studies of cues that might influence attention within visual fields.

In planning the next experiments, we used the work of Posner, Synder, and Davidson (1980) as a guide. In their studies of cuing for visual location, they found that cuing for visual location was effective only when positions were changing from trial to trial. If subjects had to direct attention to a fixed position over a block of trials, no benefit derived from knowledge of location. Because our first experiment was done with changing trials, we thought it appropriate to examine both fixed position conditions and the effects of cuing for location. Experiment 2 was carried out with all items located in a fixed position, and Experiment 3 with valid cuing provided for location shifts.

Experiment 2: Trials Blocked by Visual Field

In Experiment 2, after completing 200 divided-attention trials with random right-left presentation, the 12 subjects were told that the next 200 items would all appear to one side of the fixation point. This allowed the subject to devote attention to only one visual field with no response required to the unattended field. As in the previous experiment, appearance of an item was controlled by eye position on fixation as reported by the eye monitor. Pacing

³ A reviewer has suggested that the F test of the interaction of Condition \times Visual Field is the weakest possible test that could be performed to test this hypothesis, a planned comparison of the form $[-1(\text{RVF attended}) + 0(\text{Baseline RVF}) + 1(\text{LVF not attended})] - [-1(\text{RVF not attended}) + 0(\text{Baseline LVF}) + 1(\text{LVF attended})]$ /mean square residual, Condition \times Visual Field interaction, being the most powerful test. Although such a comparison is not strictly appropriate, following an overall ANOVA, we carried it out. The resulting value of the t statistic ($df = 11$) is .71. Note that this is the value of t , not the p value. The same comparisons done on Experiments 2 and 3 yielded somewhat smaller values of t .

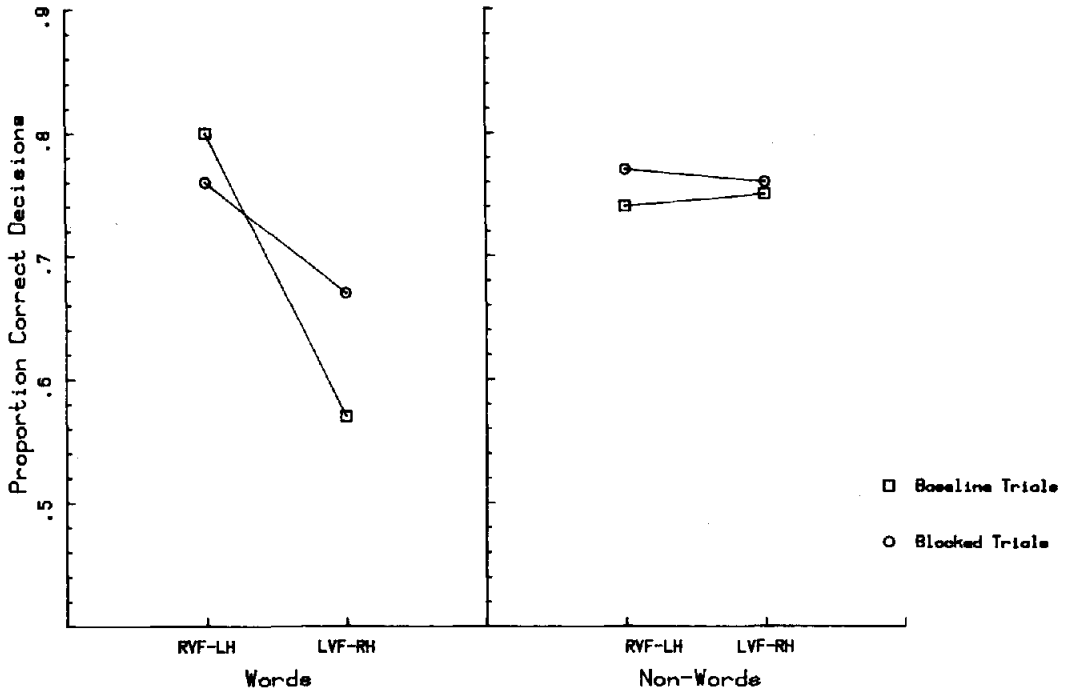


Figure 2. Experiment 2: Response accuracy in each visual field for baseline and visual field blocked conditions. (RVF = right visual field; LH = left hemisphere; LVF = left visual field; RH = right hemisphere.)

of trials was done as in Experiment 1, allowing approximately 5 s between trials. The fixation point appeared immediately following a subject's response and remained through eye position sampling, disappearing during the stimulus display and reappearing after the subject's response. Following a block of 200 trials in one visual field, a second block of trials was done in the other visual field. Results for this experiment are shown in Figure 2.

A $2 \times 2 \times 2$ repeated measures analysis of variance (decision type, baseline and blocked trials, and visual field) on response accuracy indicated significant main effects for decision type, visual field, and the interaction of Decision Type \times Visual Field (Table 1). The visual field effects are similar to those in the first experiment, indicating an RVF advantage for word judgments. Interaction effects are also similar, reflecting the differences present in visual field for judgments of words and nonwords. Ability to correctly detect a nonword remains high and with no performance differences present across visual fields. As in the previous experiment, there were no significant

findings for condition or the interaction of Condition \times Visual Field.

An analysis of variance on reaction time (Table 2) indicated significant effects for the three main conditions of decision type, condition, and visual field, and the interaction of decision type with visual field. Results are quite similar to those found in Experiment 1. Subjects respond more quickly to words in the RVF than the LVF, show improvements in speed for blocked trials relative to baseline trials, and have smaller visual field differences for nonwords. However, the baseline visual field difference is unaltered when trials are blocked by visual field.

Because Experiment 1 revealed an interaction of Condition \times Visual Field for reaction time when word decisions were analyzed separately, the same analyses were carried out for this experiment. For accuracy data, significant effects were found for the main effects of condition and visual field, with no other effects or interactions reaching significance. The corresponding analysis for reaction time also revealed significant effects for condition and vi-

sual field, the interaction of Condition \times Visual Field falling short of acceptable significance levels.

Results of this experiment are in accord with the findings of Experiment 1, as regards accuracy of judgment within the visual fields for words and nonwords. The effect of fixing position produces a result similar to that reported by Posner et al. (1980) on the lack of advantage in directing attention under conditions of fixed location. In Experiment 3, the effects of directing attention to shifting locations was examined.

Experiment 3: Position Cuing

Procedure for Experiment 3 was identical to that used in the first two experiments through the first (baseline) block of 200 trials. However, in the current experiment, prior to beginning the second block of 200 trials, subjects were told that the fixation point $><$ would now indicate the visual field location of the next item to appear—items on the right being cued by $>$ and items on the left by $<$ —and that this information was always correct. A trial was initiated by the appearance of either the RVF indicator $>$ or the LVF indicator $<$ immediately following the subjects' response to the previous trial. The left and right field indicators were randomly altered within each block of trials. Letter strings always appeared in the same location relative to the fixation point. The indicator was present during the approximately 5-s intertrial interval initiated immediately upon a subject's response and ended by the experimenter's initiating the eye position sampling. If the subject was fixated within the digital window surrounding the fixation point, the letter string appeared after an 83-ms interval (the time required to identify five steady eye fixations) and was shown for 100 ms. Following the subject's response the next position indicator appeared immediately. Subjects were reminded that fixation had to be maintained if the item was to appear and that a shifting of gaze in the direction indicated by the $>$ or $<$ would delay the appearance of the item until fixation was returned to the center of the screen.

Two blocks of 200 trials each were carried out on 12 subjects, using this cuing procedure, with a brief rest interval between trial blocks.

Eye position was recalibrated after each trial block. Results for this experiment are shown in Figure 3.⁴

A $2 \times 3 \times 2$ analysis of variance on response accuracy with the same groupings as in Experiment 1 (Table 1) indicated significant main effects for decision type, visual field, and the interaction of decision type with visual field. These results indicate differential accuracy for correctly judging words versus nonwords and the differences in accuracy rate for words only between the RVF and the LVF. The net effectiveness of the position indicators on improvement over the divided attention condition is basically zero, as indicated by the lack of any significant interaction between condition and visual field, $F(2, 22) = .50$.

Performance on correct recognition of nonwords was quite similar to that found in the first two experiments, accuracy being extremely high in both visual fields, with no effect of positional cuing.

An analysis of variance on reaction times, using the same groupings as for response accuracy, produced significant effects for decision type, condition, and visual field, and for the interaction of decision with visual field (Table 2). Reaction time data show an almost identical pattern of performance to that of the accuracy data. Response times for word recognitions are consistently faster in the RVF by an average difference (over all three conditions) of 111 ms. Although response times improved steadily from baseline through the first block of cued trials to the second block (the condition main effect), the difference between RVF times and LVF times remained virtually constant. Times for identification of nonwords are longer on the average with no significant differences between visual fields. Analyses for accuracy and reaction time carried out on words only produced significant effects for visual field in accuracy and condition and visual field in reaction time. The interaction of Condition \times Visual Field did not reach acceptable significance levels for either analysis. The positive

⁴ In this experiment our right-left cuing was randomized within each block of 200 trials. Because we thought there might be practice effects, right-left orienting is plotted separately for each block of 200 trials. We follow this practice, except for Experiment 2, where all trials in a block were shown to one side of fixation.

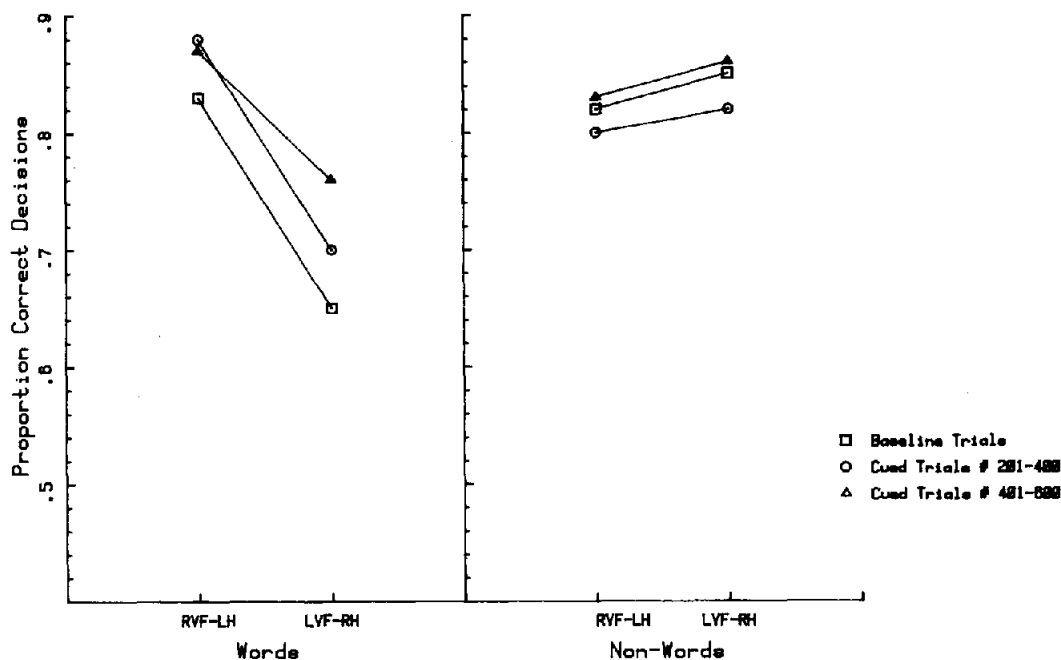


Figure 3. Experiment 3: Response accuracy within visual fields for baseline and position cued conditions. (RVF = right visual field; LH = left hemisphere; LVF = left visual field; RH = right hemisphere.)

effects of directing attention to changing locations reported by Posner et al. (1980) do not seem to be present for our task, given the lack of significant Condition \times Visual Field interactions.

Several possibilities exist for interpretation. Shulman, Remington, and McLean (1979) have shown that the course of orienting attention is time locked, reaching an optimal level at about 300–350 ms, in a sensory detection task. Our interval was much longer, being at a minimum of approximately 6 s. However, if the subject was not fixated properly, or blinked during the eye position sampling, thus initiating a new sampling sequence, the time interval prior to the actual exposure of the stimulus item could be much longer. We cannot rule out the possibility that our orienting interval was too long to observe any substantial benefits of a position cue.

In Experiment 1, after 200 divided-attention trials, the subject was instructed to devote more attention to one visual field than the other, although a field could not be entirely neglected because responses were required to items appearing in the less attended field. In

Experiment 2, attention could be devoted entirely to one visual field because items were presented at a fixed location in blocks of 200 within that field. These manipulations basically did not alter the accuracy of visual field performance relative to that found in the divided attention trials. When reaction time was examined, a shift in performance for words only was found in Experiment 1, but not in Experiment 2 or 3.

As an aid to accuracy of judgments, knowing exactly where an item will appear is almost of no help at all over random right-left presentation in making a correct decision about a word. Also, it has no effect, positive or negative, on the equal bilateral effectiveness of classifying nonwords correctly. Right and left visual field differences in accuracy in the lexical decision task are not affected at a level sufficiently beyond chance expectations by instructions, changing cues, or fixed locations. It seemed appropriate at this point to isolate both practice and possible nonspecific arousal effects that may have affected the results of Experiments 1–3, particularly the generalized improvement in reaction time observed in all

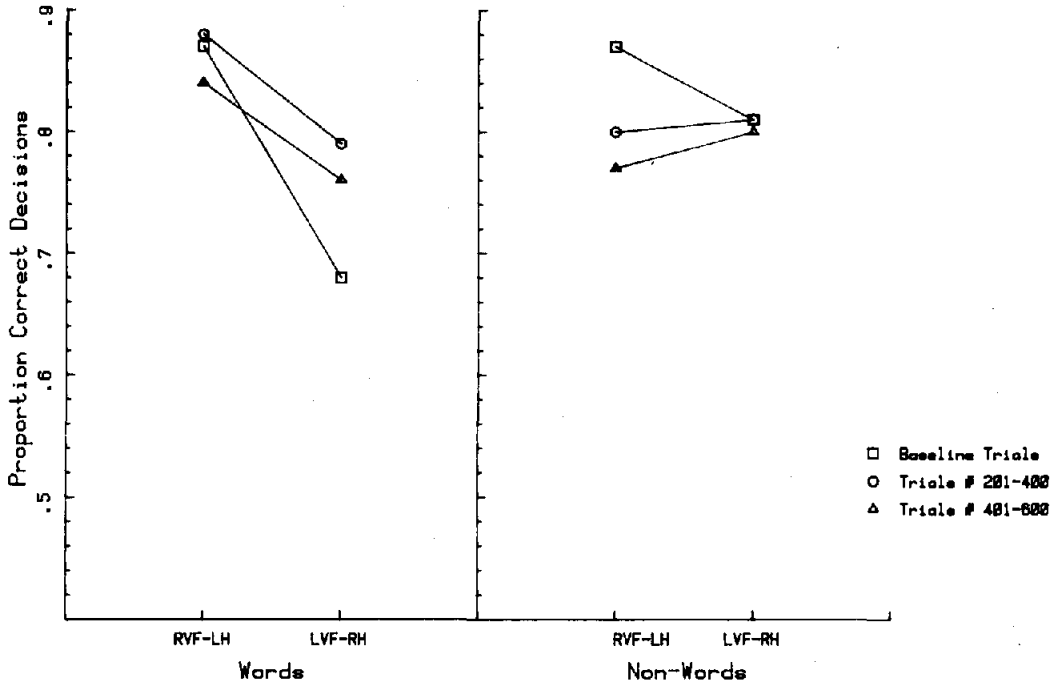


Figure 4. Experiment 4: Response accuracy within visual fields across trial blocks in the absence of attentional instructions. (RVF = right visual field; LH = left hemisphere; LVF = left visual field; RH = right hemisphere.)

attentional orienting conditions. In Experiment 4, subjects are given additional trials with no instructions or cue information at all, and in Experiment 5 subjects are exhorted to improve performance nonspecific to a spatial location.

Experiment 4: Neutral Condition

Experiment 4 was designed to assess simple practice effects and consisted of three blocks of 200 trials, each with random right-left presentation and no changes in instructions from those given at the beginning of the first trial block. Results for 6 subjects are shown in Figure 4.

An analysis of variance (Table 1) revealed significant main effects for visual field and the interaction of Decision Type \times Visual Field, results differing from previous experiments only in the failure of decision type to reach significance as a main effect. An analysis of variance of reaction times (Table 2) indicated significant main effects of decision type, condition, and visual field. Differences in performance accuracy and response times are not

distinguishable from those experiments attempting to manipulate attentional orienting.

Experiment 5: Nonspecific Improvement Instructions

In Experiment 5, 12 subjects were told after each block of 200 random right-left trials to try to improve their accuracy, but with no instruction as to location and no information as to previous performance. This condition allowed us to examine shifts in visual field performance that may have originated by subjects' attempting to improve performance by concentrating in the visual area where they felt that performance was poorer. Results for Experiment 5 are shown in Figure 5.

An analysis of variance on accuracy scores indicated significant main effects for decision type, visual field, and the interaction of decision type and visual field—results again remarkably similar to those found in Experiments 1-3 (Table 1). A reaction time analysis of variance indicated significant main effects for decision type and condition (see Table 2).

Results for these experiments closely parallel

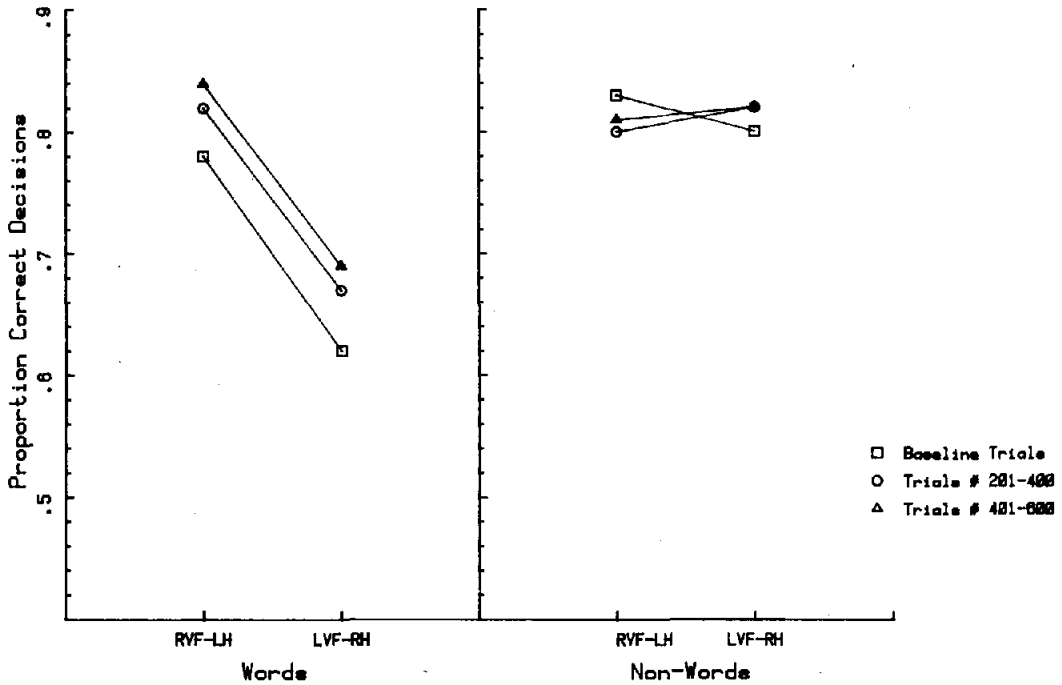


Figure 5. Experiment 5: Response accuracy within visual fields for baseline and nonspecific improvement instruction conditions. (RVF = right visual field; LH = left hemisphere; LVF = left visual field; RH = right hemisphere.)

those found in the first three experiments and seem definitive in their support of our preliminary conclusions that instructions, cues, and blocking of trials within a visual field all have essentially no effect on accuracy of performance. The analyses of variance for these two experiments produced results virtually identical to those found in Experiments 1-3. Effects found for experimental manipulations (Experiments 1-3) are no greater than simple practice effects found when no experimental changes are introduced. The apparent (i.e., nonsignificant) ability to shift orientation to a greater degree in the LVF found in Experiment 1 seems in the light of our later results to be idiosyncratic, perhaps due to the slightly lower level of performance present for that group of subjects.

As a way of assessing results over all experiments, a common standard score baseline within experiments was calculated for all subjects. Because the beginning 200 trials were identical for all experiments, the mean for each subject was set to 50 and the standard deviation to 10 using the four proportions for correct

word identification and correct nonword identification in the RVF and LVF. Then the standard scores for experimental conditions were calculated using the baseline equation. This procedure eliminates group differences in baseline performance. Thus we can examine the effectiveness of instructions, cuing, and so forth, relative to the control conditions of Experiments 4 and 5 independently of differences in level of group performance on the 200 divided-attention trials. In Figure 6, performance on the divided attention block of 200 trials is shown, and in Figure 7, the average performance for the experimental conditions (instructions, cuing) is shown.

In Figure 8, the data from Figures 6 and 7 are plotted on one graph, to illustrate the extent of shift from the baseline divided-attention condition of the first 200 trials to the effects present in the second and third blocks of trials. A similar analysis was done for reaction times. The results are so similar to the accuracy data that there seems little point in presenting a detailed account. Inspection of these figures confirms our previous interpretations: Even

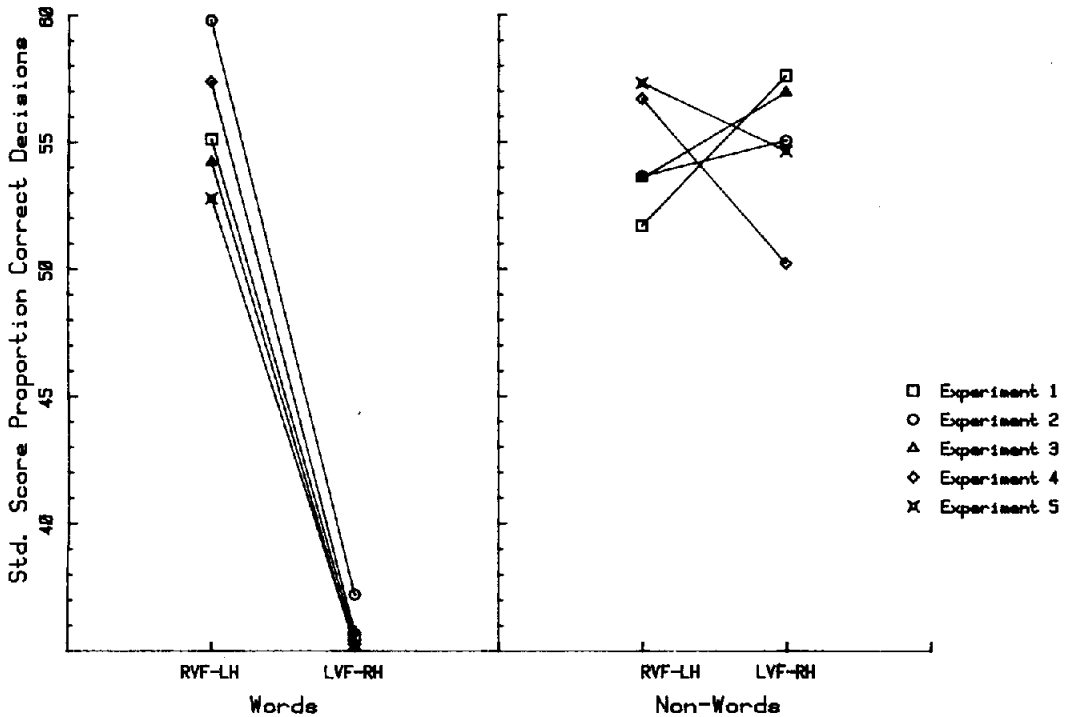


Figure 6. Experiments 1-5: Standardized (Std.) response accuracy scores for baseline conditions. (RVF = right visual field; LH = left hemisphere; LVF = left visual field; RH = right hemisphere.)

when minimizing group differences, we find no effect of attentional orienting over and above simple practice effects.

General Discussion

There are two aspects of these five experiments that are of interest: the lack of effect of any of our experimental manipulations on accuracy or speed of response within visual fields and the striking difference in visual field accuracy of word identification as compared to nonword identification. The latter finding (RVF advantage for words, equivalent VF performance for nonwords) has been reported previously (e.g., Brandt, Van Bekken, Stumpel, & Kroeze, 1983; Chiarello, Dronkers, & Hardyck, 1984; Leiber, 1976) and may be related to other findings of differential laterality effects for positive and negative decisions (e.g., Hellige, Cox, & Litvak, 1979). Because the present study was not designed to investigate this phenomenon, and our attentional manipulations were not differentially effective for

word and nonword stimuli, we will refrain from post hoc interpretations of this finding. We do point out that within a signal detection analysis framework the RVF "hit" rate was substantially higher than that obtained in the LVF, under conditions of identical false alarm rates across the visual fields. This refutes any suggestion that visual field differences in response bias account for our observed laterality effects.

The primary focus of our data is, of course, the constant and apparently unchangeable difference in correct decisions between the right and left visual field presentations. Experiments 2 and 3 are of special interest in this regard. Subjects, when given completely valid information about the location of an item, are unable to improve performance in the LVF-RH. After 400 trials, improvement is no greater than occurs with no location information at all in a divided-attention situation, other than simple practice. When compared with the striking results obtained by Posner and his colleagues, this apparent inability to spatially

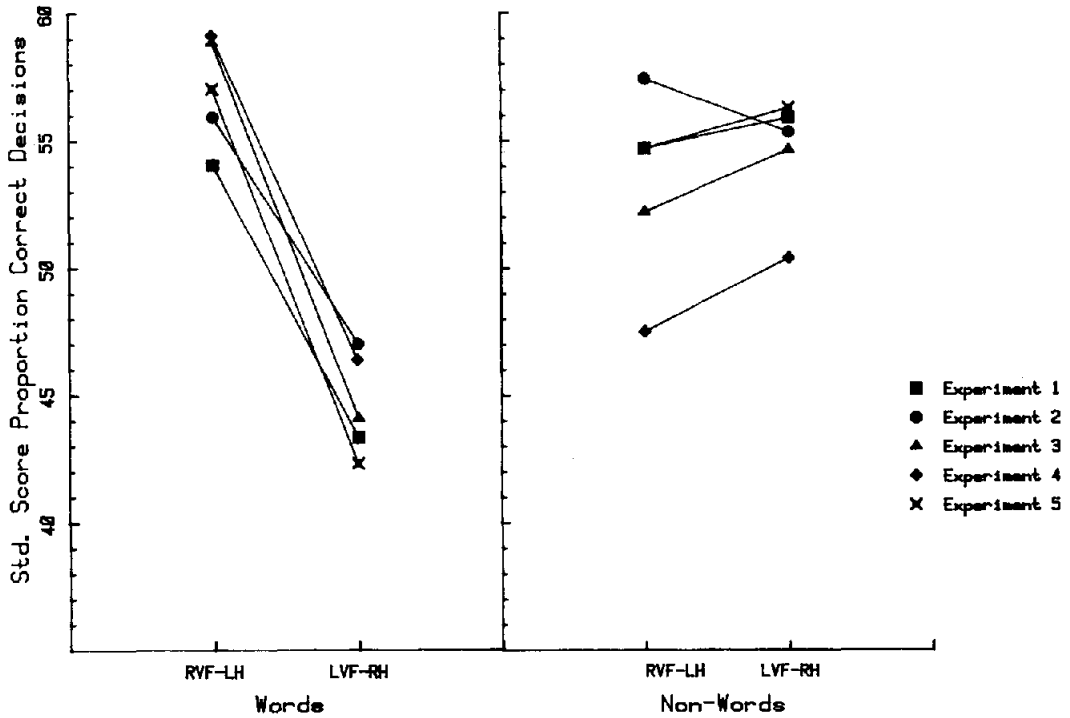


Figure 7. Experiments 1-5: Standardized (Std.) response accuracy scores for experimental conditions. (RVF = right visual field; LH = left hemisphere; LVF = left visual field; RH = right hemisphere.)

orient is all the more surprising. Attention may be spatially oriented without eye movements, but if the task to be undertaken involves lexical decisions, this ability will not be of any detectable benefit. Apparently the demands of the necessary cognitive operations and the differential capacity of the cerebral hemispheres to do these operations suffice to render any orienting advantage insignificant. Although a significant Condition \times Visual Field difference in reaction time for word decisions alone was found for Experiment 1, this difference failed to appear in the later experiments. Thus, although it appears that our instructions facilitated response time, later manipulations that should have produced similar effects did not reach an acceptable level of significance.

This suggests that processing facilitation due to focusing of spatial attention (e.g., Posner et al., 1978; Shulman et al., 1979) may be limited to the *detection* of signals, and not extendable to cognitive *decisions* about the nature of the signal. This is in accord with an earlier sug-

gestion by Posner (1980). However, the most important aspect of our results is the finding of a stable visual field (and by inference, hemispheric) asymmetry that could not be altered by subject-directed shifts in attention. This finding offers considerable support to the position that the asymmetries reflect processing differences between the cerebral hemispheres. Although this conclusion is based on an acceptance of the null hypothesis, the cumulative results of five experiments support this interpretation. It will be of interest to see if visual field asymmetries for other tasks are equally resistant to manipulation of attention. Our results do not, of course, negate Bryden's (1980) findings on dichotic listening, but do suggest that attentional biases are not intrinsic to all observed laterality effects.

Based on our results, we suggest the following: (a) There are marked differences in lexical decision ability between cerebral hemispheres, even under conditions where these differences should be minimized. (b) These differences in

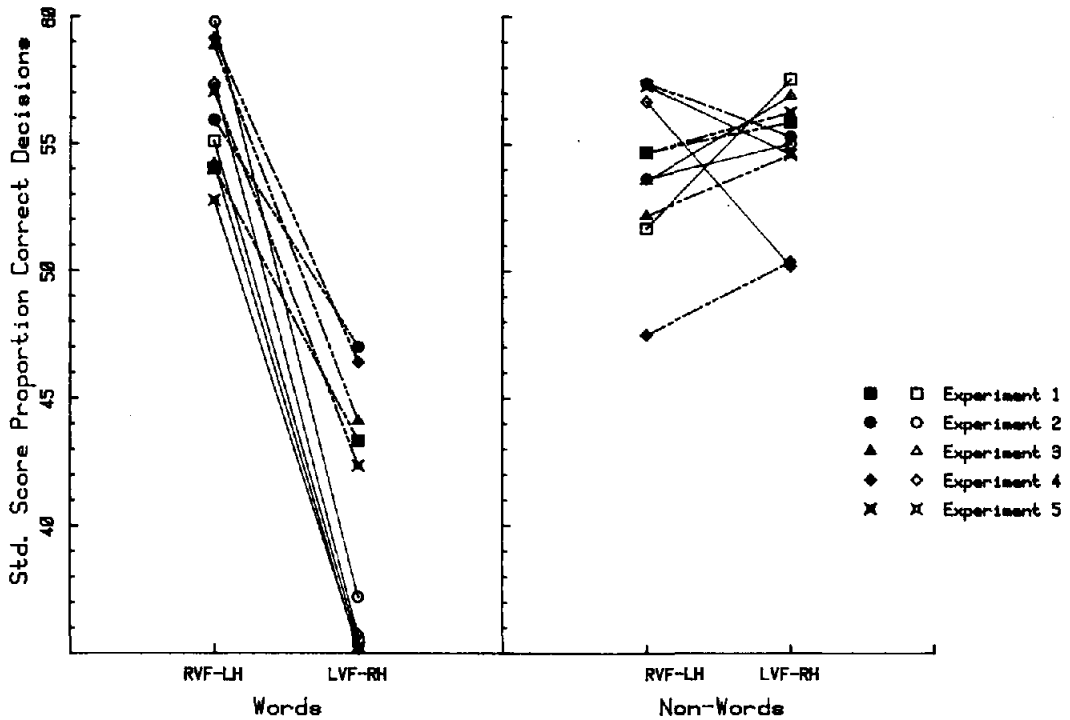


Figure 8. Experiments 1-5: Standardized (Std.) response accuracy scores for baseline and experimental conditions. (Open symbols represent baseline conditions; filled symbols represent experimental conditions. RVF = right visual field; LH = left hemisphere; LVF = left visual field; RH = right hemisphere.)

performance (unlike some auditory differences) are not explainable, even in part, by attentional bias. (c) There is little evidence for any sharing of resources between hemispheres for the lexical decision task; even under conditions (Experiment 2) where all available resources could be devoted to one visual field-hemisphere, no change in asymmetries was observed. Both hemispheres appear to be working at maximum capacity to perform the designated tasks, using the resources available within a hemisphere.

Support for this interpretation comes from a recent study of lexical decision performance in split brain patients (Zaidel, 1983). Five of the six patients tested could make lexical decisions to stimuli directed to either visual field/hemisphere, with a slight but significant advantage for RVF stimuli. The result is quite similar to our own with normal subjects and lends support to the inference that the observed visual field differences primarily reflect hemi-

sphere of input performance differences for the lexical decision process.

In offering such an explanation, one must consider alternative explanations that are often offered for such discrepancies in performance. A left-to-right scanning bias derived from reading habits might favor RVF stimuli, because left-most letters in this field are closer to the fovea. However, such an explanation cannot account for our reliable findings of RVF advantages for word, but not nonword, strings. A scanning bias of any sort should produce a visual field advantage without regard for lexical category, instead of the similarity of performance found for our nonword strings.

A second interpretation for visual field differences is the hypothesis that information received in one hemisphere is sent to the appropriate hemisphere for analysis but undergoes serious signal degradation during the transfer. At present such a possibility cannot be refuted, but the most appropriate rejoinder is that of

Cohen (1982), who argues that it is difficult to conceive of a system that permits accurate transmission of signal information from a sense organ to a given area of the brain but does not permit accurate transfer of this information from one area of the cortex to another without serious loss of fidelity—in our experiments an error rate difference of .20.

In our experiments, the maximum knowledge possible existed about the location of an item, and the type of decision process to be carried out was well practiced by the midpoint of any experimental session. If the mechanism of interhemispheric transfer is working at maximum efficiency and still produces visual field differences with error rates of .20, then it seems that some of the early speculations about the relative *unimportance* of the corpus callosum should be resurrected and treated with more deference. It should also be pointed out that an error process that works in only one direction—producing an increase in wrong judgments about words but not about nonwords—presents a considerable challenge of explication.

However, we should briefly consider an alternate explanation that does incorporate bi-hemispheric involvement in processing LVF stimuli. Perhaps the hemispheres are equally capable for determining that a nonword stimulus has no semantic referent, but evidence sufficient for word decisions requires information available only to the left hemisphere. This approach assumes that nonwords are processed in the hemisphere of input, but LVF word decisions require callosal transfer. Of course, one problem with such a model is the necessity to posit a decision rule for the right hemisphere to determine when to transfer stimulus information to the left hemisphere (words—yes; nonwords—no). It is difficult to conceive of such a rule not tantamount to making the lexical decision within the right hemisphere. Although we cannot rule out such an interpretation, it appears unlikely on an a priori basis.

In summary, consideration of possible explanatory mechanisms for our cumulative results is supportive of a position postulating separate, unequal, and unshared processes for lexical decision processes within the cerebral hemispheres. As an explanatory framework

from which testable predictions can be made, it is clearly superior to the “degradation during callosal transfer” hypothesis.⁵ It is also reasonable to consider the possibility that such a dual-processor system is limited to certain language functions and will not serve as an explanatory model for visuospatial processes in cognition. Most important, our results indicate that attentional biases can be effectively eliminated as a source of variation in visual field effects, at least for lexical decision tasks. Unlike the effects found for auditory stimuli (Bryden, 1980), the present findings indicate that at least some visual field asymmetries are stable, unalterable by attentional factors, and thus may be reasonably direct measures of processing differences in the cerebral hemispheres.

References

- Barry C. (1981). Hemispheric asymmetry in lexical access and phonological encoding. *Neuropsychologia*, 19, 473–478.
- Beaumont, J. G. (Ed.). (1982). *Divided visual field studies of cerebral organisation*. London: Academic Press.
- Bradshaw, J. L., & Gates, E. M. (1978). Visual field differences in verbal tasks: Effects of task familiarity and sex of subject. *Brain and Language*, 5, 166–187.
- Bradshaw, J. L., & Nettleton, N. C. (1981). The nature of hemispheric specialization in man. *The Behavioral and Brain Sciences*, 4, 59–91.
- Brandt, N., Van Bekken, I., Stumpel, M., & Kroeze, J. M. A. (1983). Word matching and lexical decisions: A visual-half field study. *Brain and Language*, 10, 199–211.
- Bryden, M. P. (1980). Attentional factors in the detection of hemispheric asymmetries. In G. Underwood (Ed.), *Strategies of information processing* (pp. 571–582). New York: Academic Press.
- Chiarello, C., Dronkers, N. F., & Hardycy, C. (1984). Choosing sides: On the variability of language lateralization in normal subjects. *Neuropsychologia*, 22, 363–373.
- Cohen, G. (1982). Theoretical interpretations of lateral asymmetries. In J. G. Beaumont (Ed.), *Divided visual field studies of cerebral organisation* (pp. 87–111). London: Academic Press.
- Coltheart, M. (1980). Lexical access in simple reading tasks.

⁵ A model incorporating the characteristics we have described here has been proposed by Friedman and Polson (1981) and supported by additional work (Friedman, Polson, Dafoe, & Gaskill, 1982). Because our work was not carried out as a test of this model, we have refrained from interpreting our data in terms of this framework and will note that it seems the most appropriate descriptive framework for our data.

- In G. Underwood (Ed.), *Strategies of information processing* (pp. 151-216). London, Academic Press.
- Corballis, M. C. (1983). *Human laterality*. New York: Academic Press.
- Eriksen, C. W., & Hoffman, J. E. (1973). The extent of processing of noise elements during selective encoding from visual displays. *Perception & Psychophysics*, *14*, 155-160.
- Friedman, A., & Polson, M. C. (1981). Hemispheres as independent resource systems: Limited-capacity processing and cerebral specialization. *Journal of Experimental Psychology: Human Perception and Performance*, *7*, 1031-1058.
- Friedman, A., Polson, M. C., Dafoe, C., & Gaskill, S. (1982). Dividing attention within and between hemispheres: Testing a multiple resources approach to limited-capacity information processing. *Journal of Experimental Psychology: Human Perception and Performance*, *8*, 625-650.
- Hardyck, C. (1983). Seeing each other's points of view: Visual perceptual lateralization. In J. B. Hellige (Ed.), *Cerebral hemisphere asymmetry: Method, theory and research* (pp. 219-254). New York: Praeger.
- Hellige, J. B., & Cox, P. J. (1976). Effects of concurrent verbal memory on recognition of stimuli from the left and right visual fields. *Journal of Experimental Psychology: Human Perception and Performance*, *2*, 210-221.
- Hellige, J. B., Cox, P. J., & Litvak, L. (1979). Information processing in the cerebral hemispheres: Selective hemispheric activation and capacity limitations. *Journal of Experimental Psychology: General*, *108*, 251-279.
- Kinsbourne, M. (1975). The mechanisms of hemisphere control of the lateral gradient of attention. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and performance V* (pp. 81-97). New York, Academic Press.
- Klein, R. (1979). Does oculomotor readiness mediate cognitive control of visual attention? *Attention and performance VIII*. Hillsdale, NJ: Erlbaum.
- Leiber, L. (1976). Lexical decisions in the right and left hemispheres. *Brain and Language*, *3*, 443-450.
- Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh Inventory. *Neuropsychologia*, *9*, 97-113.
- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3-25.
- Posner, M. I., Nissen, M. J., & Ogden, W. C. (1978). Attended and unattended processing modes: The role of set for spatial location. In H. L. Pick & I. J. Saltzman (Eds.), *Modes of perceiving and processing information* (pp. 137-158). Hillsdale, NJ: Erlbaum.
- Posner, M. I., Snyder, C. R. R., & Davidson, B. J. (1980). Attention and the detection of signals. *Journal of Experimental Psychology: General*, *109*, 160-174.
- Remington, R. W. (1980). Attention and saccadic eye movements. *Journal of Experimental Psychology: Human Perception and Performance*, *6*, 726-744.
- Shaw, M. L. (1978). A capacity allocation model for reaction time. *Journal of Experimental Psychology: Human Perception and Performance*, *4*, 586-598.
- Shulman, G. L., Remington, R. W., & McLean, J. P. (1979). Moving attention through visual space. *Journal of Experimental Psychology: Human Perception and Performance*, *5*, 522-526.
- Toglia, M. P., & Battig, W. F. (1978). *Handbook of semantic word norms*. Hillsdale, NJ: Erlbaum.
- Van Voorhis, S., & Hillyard, S. A. (1977). Visual evoked potentials and selective attention to points in space. *Perception & Psychophysics*, *22*, 54-62.
- Zaidel, E. (1983). Disconnection syndrome as a model for laterality effects in the normal brain. In J. B. Hellige (Ed.), *Cerebral hemisphere asymmetry: Method, theory and application* (pp. 95-151). New York: Praeger.

Received April 12, 1984

Revision received May 24, 1985 ■