On the Representation of Language in the Right 
Hemisphere of Right-Handed People

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Laterality experiments using reaction time were conducted to assess the performance of the right hemisphere of normal people on verbal tasks. The results show that if the task calls for pictorial encoding of visually presented verbal material, then the right hemisphere's performance is superior to that of the left. When the task calls for linguistic analysis, the minor hemisphere displays no aptitude in dealing with the task. The latter finding is at variance with data from split-brain research. To reconcile these differences, it was proposed that language functions, thought represented in the right hemisphere of normal people, are functionally localized in the left. When the control which the left hemisphere exerts over the right is weakened or removed, e.g., by commissurotomy, right hemisphere language is released. The application of this model to other neurological phenomena is briefly discussed.

INTRODUCTION

The demonstration that the right, minor hemisphere exhibited a wide range of linguistic skills was one of the more revealing aspects of studies conducted on a group of patients with surgical disconnection of the cerebral hemispheres. Sperry, Gazzaniga, Bogen and their collaborators (for reviews see Bogen, 1969a,b; Gazzaniga, 1970; Sperry, 1968; Sperry, Gazzaniga & Bogen, 1969) found that the minor hemisphere can comprehend some spoken and written language. In contrast to the dominant, left hemisphere, the minor hemisphere is almost mute and its comprehension is limited to spoken and written nouns, some phrases, and very simple sentences. Even so, the minor hemisphere has reasonably sophisticated verbal concepts for the material it comprehends. For example, it understands that a "match" is "used to light fires," that a "ruler" is a "measuring instrument," and that a "glass" is a "liquid container."

1 A paper based on these experiments was presented at the Eastern Psychological Association in Washington, 1973. Experiment 3 was part of a doctoral dissertation in psychology at the University of Pennsylvania which was supported, in part, by NSF Grant GB 8013 to Paul Rozin. The rest of the research was supported by an NRC of Canada grant to the author. I thank Dr. Paul Rozin, my advisor, whose encouragement and suggestions at all stages of this work were invaluable. I also thank Jerre Levy and Danny Klein for their many helpful comments and criticisms of earlier versions of this paper.

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These findings led Sperry and his associates to propose that language is represented in both hemispheres, though more strongly in the left. This does not mean that the correspondence between the right hemisphere’s linguistic performance and its linguistic capacity will be as close in other people as it is in split-brain patients. For example, when the interhemispheric pathways are intact, they may allow the left hemisphere to influence the right and so obscure the right hemisphere’s linguistic skill. This point was emphasized by Sperry et al. (1969) and by P. Milner (1970) in explaining the surprisingly poor linguistic performance of some aphasic people with normal, healthy right hemispheres, and by Moscovitch (1972, 1973) in discussing the linguistic performance of the right hemisphere of normal people. According to this view, it is possible that language may be represented more or less equally in the right hemisphere of all people, but may appear to be functionally more lateralized in some than in others.

To test this hypothesis, a series of experiments was begun a few years ago to assess the linguistic performance of the right hemisphere of normal people (Moscovitch, 1972, 1973; Moscovitch & Catlin, 1970). The results of these experiments suggested that the linguistic performance of the right hemisphere of normal people did not seem to match its true linguistic capacity as established by the split-brain research. The present experiments extend the earlier observations and confirm the impression that whatever the linguistic competence of the right hemisphere might be, language in normal people is functionally localized in the left hemisphere.3

The general design and logic were similar to the previous experiments. Stimuli were presented to the right or left visual field and the subject responded with either his left or right hand. Differences in reaction time (RT) between visual fields indicate which hemisphere is superior at executing the task at hand. Thus, reaction time to stimuli that require linguistic analysis favor the right visual field-left hemisphere while those that require only pictorial–spatial analysis favor the left visual field–right hemisphere (Cohen, 1972; Geffen, Bradshaw & Wallace, 1971; Geffen, Bradshaw & Nettleton, 1973; Gibson, Filby & Gazzaniga, 1970; Klatzky, 1970; Klatzky & Atkinson, 1972; Moscovitch, 1972, 1973;

3 It should be emphasized at the outset that it is not the purpose of the paper to determine whether the right hemisphere’s capacity to comprehend and to convey verbal information is “linguistic” in the sense that linguists, of whatever stripe, use this term. The purpose, rather, is to determine why some of those capacities are reflected in performance in some situations but not in others. These capacities, limited as they are, are termed “linguistic” because they seem necessary for dealing with linguistic utterances such as words, phrases and sentences. Questions regarding the properties of right hemisphere language and their congruence with the properties of normal language are left for later research (but see General Discussion).
In addition, by manipulating stimulus-response connections it is possible to determine the relative contribution of a number of factors to the reaction-time difference. Those factors include hemispheric efficiency in executing the task at hand, interhemispheric transmission time, and attention. For example, if reaction times favor the same visual field by a constant amount regardless of responding hand, it indicates that some or all of the task must be mediated by the hemisphere contralateral to that visual field. If, however, reaction times favor the visual field on the same side as the responding hand or if the size of the reaction time difference changes with responding hand, it suggests either that both hemispheres perform that particular task equally well or that one does so more efficiently than the other (see Moscovitch, 1973, for a more detailed exposition). This kind of analysis should enable us to evaluate the performance of each hemisphere on some linguistic tasks.

**EXPERIMENT 1**

In an earlier experiment, Moscovitch (1972) found that when subjects matched a visually presented probe letter to a letter presented binaurally two seconds earlier, RTs favored the left visual field for a left-hand response and neither field for a right-hand response. There are two ways to interpret this result. Either the minor hemisphere compared the two letters along a linguistic dimension, i.e., by matching their names, or the subject converted an ostensibly linguistic task to one that can be solved using only pictorial skills. The subject could have accomplished the latter by evoking a visual representation of the acoustically presented letter and matching the test and set letters according to shape.

Experiment 1 tested whether the hemispheres compared the letters linguistically or pictorially. On half the trials the subject saw a probe or test letter that is different from the acoustic set letter, but resembles it either pictorially, e.g., E-F, or acoustically, e.g., E-D. A match based on shape or “physical” (Posner, 1969) features should make it more difficult for the subject to discriminate between pictorially similar pairs than between acoustically similar pairs and should be reflected in longer RTs to the pictorially similar pairs. If the subject uses a linguistic strategy and compares the names of the two letters, then acoustically similar pairs will yield longer RTs.

**METHOD**

*Subjects.* Sixteen right-handed students at Erindale College participated in the experiment. None was aware of the exact purpose of the experiment. Half the subjects responded with the right hand and the other half with the left. Within each of these two groups, the subjects were matched so that test letters that appeared in one visual field for one subject appeared in the opposite field for another subject.
Apparatus. Ready signals and memory sets were recorded on tape (33 1/3 speed) and delivered to the subject via earphones. The test letters were presented by two rear-screen stimulus projectors (Industrial Electronic Engineers, In-line Readouts, Series 80). The projectors were at the rear of a black panel. The faces of the projectors were flush with the panel and located 3.2 cm on either side of a fixation point in the center of the panel. Presentation of the test letters started a timer (Monsanto) that was accurate to 10⁻² msec. Closure of microswitches that were out of view but situated on a table directly before the subject stopped the timer. The timer, the tape recorder, the control panel, and the experimenter were all in a room separate from the subject.

Procedure. The subject wore earphones and sat facing the panel which was about 75 cm away. He rested his hand on a table and placed his index finger between two microswitches. All auditory input was presented binaurally and at a comfortable sound level. When he heard the word “ready,” the subject fixated on a small white hole in the middle of the panel. Two seconds later he heard a single letter (set) followed 2 sec later by a white letter (test) that appeared for 100 msec, approximately 6° peripherally in either the right or left visual field. Half the subjects pulled on a microswitch with their index finger if the test and set letters were the same (positive set, “same” judgement) and pushed on a microswitch if they were different (negative set, “different” judgement). The mode of response was reversed for the other half. To promote speed and accuracy the subject received $32.00 at the start of the experiment from which $0.01 was deducted for every 100 msec it took him to respond and $0.25 for every mistake he made. Subjects whose error rate consistently exceeded 5% were dropped from the experiment. All RTs greater than 1000 msec were discarded. These occurred on less than 1% of the trials.

The events between the presentation of a ready signal and the subject’s response marked a trial. The first day was a practice day during which the subject ran through two sessions of 40 trials each. On the following three days, the subject received a total of 480 trials, which were divided into 10 sessions of 48 trials each. Each session was in turn divided into 6 blocks of 8 trials. The subject was unaware of this division. A block contained two negative and two positive trials in both the right and left visual fields. The trials were randomized within blocks, and the blocks within sessions, so that no two sessions were alike. Over an entire session the negative trials within each visual field were randomized so that on half the trials the test-set pairs were pictorially similar and the other half were acoustically similar. A trial occurred every 10 sec making each session last 8 min. Unless the subject complained of fatigue, he received 4 sessions a day and 2 sessions on the last day. The subject was encouraged to take 5-10 min breaks between sessions. During part of the break the experimenter told the subject approximately how much money he was earning.

The instructions given the subject followed the steps of the procedure just described. The purpose of the experiment or any other information which might bias the results were withheld from the subject until the experiment was completed.

Before being admitted to the experiment, each subject was pretested for acuity on a Snellen chart. Pretests for handedness required him to sign his name on a “subject sheet” and to reach quickly for an object. The tests were conducted without the subject’s knowing their true purpose. Unless a subject was judged to be right-handed on the pretests and had about equal satisfactory eyesight in each eye, he was not accepted into the experiment. Following the experiments the subject was questioned in detail to determine whether he was indeed right-handed. If he showed signs of ambidexterity his data were discarded.

Stimuli. The acoustic set letters were C, E, X, and Y. For “same” judgements (positive set) each acoustic letter was followed by its visual counterpart. The negative set consisted of 4 pairs of visual test letters, each member of the pair being matched for either pictorial or acoustic similarity with one of the letters from the acoustic set. Thus, for “different” judgements, C was always followed by either O or T; E, by F or D; X, by Z or S; and Y, by V or I. The test letters were all in capitals. Each letter was 5.4 cm high and, depending
on the letter, 1.6 to 6.0 cm wide. The letters appeared white on a black background and at an average luminance of 19 foot lamberts.

RESULTS

The results are summarized in Table 1 and aspects of them are highlighted in Fig. 1. Separate analyses of variance were conducted for “same” and “different” judgements. For “same” judgements, a two-way analysis of variance with one between-factor (response hand) and one within-factor (visual field) showed a significant visual field by response hand interaction \[ F(1,14) = 4.80, p < .05 \], RTs significantly favoring the left visual field (LVF) for a left-hand response by 23 msec \( (t(7) = 3.25, p < .01) \), but favoring the right visual field (RVF) by an insignificant 5 msec \( (t(7) = .21, p > .1) \) for a right-hand response. No other significant effects were found.

For “different” judgements, a three-way analysis of variance with one between (response hand) and two within (visual field and similarity) factors showed only a significant main effect of similarity, \[ F(1,42) = 67.69; p < .001 \] pictorially similar pairs yielding larger RTs than acoustically similar pairs, the difference being 28 msec. Overall RTs for “different” judgements favor the RVF by 6 msec, but the effect is not significant.

The number of errors was small (see Fig. 1). The difference in the number of errors between visual fields for “same” judgements was small. For “different” judgements, the error data parallel the RT data, the subjects making many more incorrect responses when the set-test pairs were pictorially similar, 64, than when they were acoustically similar, 23, regardless of response hand or visual field.

DISCUSSION

Both RT and error data attest to the greater difficulty the subject experienced in discriminating between pictorially similar as compared to

TABLE 1
Consecutive Letter-Matching Task

<table>
<thead>
<tr>
<th></th>
<th>Same</th>
<th>Different</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LVF</td>
<td>RVF</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>P</td>
</tr>
<tr>
<td>LVF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left hand</td>
<td>500 (26)</td>
<td>523 (37)</td>
</tr>
<tr>
<td></td>
<td>527 (5)</td>
<td>550 (13)</td>
</tr>
<tr>
<td>Right hand</td>
<td>459 (20)</td>
<td>454 (22)</td>
</tr>
<tr>
<td></td>
<td>510 (6)</td>
<td>542 (21)</td>
</tr>
</tbody>
</table>

* Mean RT (msec) of correct responses averaged over subjects and broken down by response hand, visual field (LVF vs RVF), type of judgement (same vs different) and similarity of set-test pairs (acoustic (A) vs pictorial (P)). The number in parentheses next to the RT designates the number of errors in that condition.
Fig. 1. Mean RT and total errors for "different" judgements in the consecutive letter matching task averaged over subjects and response hand, and broken down by visual field and similarity (pictorial (visual) vs acoustic). Dotted column, visual similarity; diagonally lined column, acoustic similarity.

acoustically similar pairs regardless of whether they responded with their right or left hand or whether the test item appeared in the right or left visual field. These results suggest that the subjects used pictorial strategies to compare ostensibly linguistic material, and would explain why RTs favor the LVF for a left-hand response in the "same" condition. These results are consistent with a great deal of neurological and behavioral evidence showing the superiority of the right hemisphere on pictorial-spatial tasks (Milner, 1971). The results also confirm earlier reports (Cohen 1972; Geffen et al., 1973; Gibson, Dimond & Gazzaniga, 1972; and Klatzky & Atkinson, 1972) that pictorial matches between letters or words favor the right hemisphere. It should be noted, however, that the left hemisphere can also operate in a pictorial modality. Results showing that right-hand responses slightly favor the RVF and that pictorial similarity causes the same difficulty when the visual test letter appears in the right visual field support this idea. Whether the left hemisphere's style of operation in the pictorial modality is similar to that of the right hemisphere cannot be determined from these data.
It is difficult to interpret why RTs for "different" judgements do not conform to the pattern of RTs for "same" judgements. RTs for "different" judgements slightly favor the right visual field, regardless of response hand. One way to explain the anomaly is to assume, as others have (see Egeth & Blecker, 1971), that in comparison to the "sameness" detector, the "difference" detector is relentless in its examination of the features of the test stimulus. Because of this, the subject will occasionally consult both hemispheres as a precaution before responding "different," but rely on the judgement of either hemisphere alone when responding "same." Consistent with this interpretation are the longer RTs for "different" judgements. It is interesting to note that so far investigators have found discrepancies between "same" and "different" judgements with regard to laterality only for stimuli such as letters that can be encoded easily either pictorially or linguistically (Cohen, 1972; Egeth & Epstein, 1972; Moscovitch, 1972) and may, therefore, engage both right and left hemisphere processes.

EXPERIMENT 2

The right hemisphere's performance in the first experiment depended on its having an internal visual representation of the acoustic letter. It could have acquired this image in one of two ways. The first is that the minor hemisphere, as well as the dominant, analysed the acoustic stimulus into its constituent phonemes, determined the name of the letter, and used this linguistic information to generate the corresponding visual image. The second possibility is that linguistic analysis of the acoustic stimulus occurs only in the dominant hemisphere, the results of which are transferred to the minor side before the test letter appears. The second experiment was designed to eliminate one of these possibilities, thereby adding information about the minor hemisphere's linguistic performance.

In Experiment 2, the acoustic set and visual test letters were presented simultaneously. It was hypothesized that if the minor hemisphere treats the acoustic and visual letters as linguistic stimuli, then it should find it more difficult to distinguish between letters that share phonemic features than it did in the previous experiment because now the acoustic trace will have no time to fade and weaken before the test letter appears. In other words, the difference in RT between pictorially and acoustically similar pairs obtained when the set-test pairs were presented successively (Expt 1) should become smaller now that they are presented simultaneously (Expt 2). If, however, the minor hemisphere treats the set and test letters as nonlinguistic, acoustic and pictorial stimuli, respectively, it should perform exactly as it did in the successive presentation condition. The dominant hemisphere, being sensitive to linguistic fea-
tures, should show the predicted change in performance regardless of the behavior of the minor side.

METHOD

Subjects. Sixteen right-handed students at Erindale College participated in the experiment. Half the subjects responded with the right hand, the other half with the left. The apparatus, stimuli, and procedure were identical to those used in Experiment I except that the acoustic set letter and visual test letter were presented simultaneously instead of successively. The onset of the acoustic stimulus activated a Schmitt trigger that started the delivery of the test stimulus.

RESULTS

The results are summarized in Table 2 and aspects of them are highlighted in Fig. 2. Separate analyses of variance were conducted for "same" and "different" judgements. For "same" judgements, a two-way analysis of variance with response hand as the between factor and visual field as the within factor showed no significant main effects or interactions. For "different" judgements, a three-way analysis of variance with response hand as the between factor and visual field and similarity as the within factors showed a significant main effect of similarity, pictorially similar test–set pairs yielding longer RTs than acoustically similar pairs, 595 to 568 msec. \( F(1,42) = 57.00, p < .001 \), and a significant visual field by similarity interaction, the difference in RT between pictorially and acoustically similar pairs being larger when the test letter appears in the LVF, (36 msec) than when it appears in the RVF (18 msec) \( F(1,42) = 5.03; p < .05 \).

As in Experiment 1, very few errors were made. The error data, however, parallel the RT data (see Fig. 2). More errors were made in distinguishing pictorially similar from acoustically similar pairs, 76 to 33. Also the difference between pictorial and acoustic confusions was greater in the LVF (34) than in the RVF (9).

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>SIMULTANEOUS LETTER MATCHING TASK*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>Different</td>
</tr>
<tr>
<td>LVF</td>
<td>RVF</td>
</tr>
<tr>
<td>A</td>
<td>P</td>
</tr>
<tr>
<td>Left hand</td>
<td>521 (23) 520 (24)</td>
</tr>
<tr>
<td>Right hand</td>
<td>529 (34) 530 (20)</td>
</tr>
</tbody>
</table>

* Mean RT (msec) of correct responses averaged over subjects and broken down by response hand, visual field (LVF vs RVF), type of judgment (same vs different) and similarity of set–test pairs (acoustic (A) vs pictorial (P)). The number in parentheses next to the RT designates the number of errors in that condition.
FIG. 2. Mean RT and total errors for "different" judgements in the simultaneous letter-matching task averaged over subjects and response hand, and broken down by visual field and similarity (pictorial (visual) vs acoustic). Dotted column, visual similarity; diagonally lined column, acoustic similarity.

DISCUSSION

The results show that the right and left hemisphere execute the same matching task in different ways. When the test stimulus projects to the right hemisphere the difference in RT between pictorially and acoustically similar items is significantly greater than when it projects to the left. The minor hemisphere compares the items along a pictorial dimension, as it did in Experiment 1. The dominant hemisphere also compares the letters primarily along a pictorial modality, but its sensitivity to linguistic features makes it more likely than the minor hemisphere to confuse pairs whose names sound alike and less likely to confuse pairs that look alike. This interpretation would account for the significant visual field by similarity interaction and is consistent with the error analysis. The difference between the number of false positive responses made to pictorially similar pairs as compared to acoustically similar pairs is greater in the minor than in the dominant hemisphere.

Figure 3 emphasizes the difference in processing strategies that the hemispheres assumed in Experiments 1 and 2. When a 2-sec delay is introduced between the presentation of the acoustic set letter and the visual test letter, both hemispheres relied on a pictorial strategy as
evidenced by the identical RT differences of 28 msec between visually and acoustically similar pairs regardless of the visual field in which the test stimulus appeared. In the second experiment, the simultaneous presentation of the set and test stimulus enhanced the interfering effects which the trace of the acoustic stimulus produced. The interference, however, was selective, affecting the dominant but not the minor hemisphere. This suggests that only the dominant hemisphere is aware of the linguistic relation between the acoustic and the visual stimulus. It further suggests that the normal minor hemisphere is dependent on the dominant one for the linguistic analysis necessary in the identification of the name of the letter from the acoustic stimulus and, ultimately, for the generation of the visual representation of that name. Whether the dominant hemisphere transmits this information to the minor one in a visual code or in another non-linguistic code cannot be determined from the present experiment.

Another interpretation may explain the minor hemisphere’s failure to exhibit linguistic skills in the simultaneous matching task. It may be that the minor hemisphere attends to the linguistic features of acoustic stimuli if it is not distracted by additional information. The present experi-
ment, however, requires it to process acoustic and visual information simultaneously and under these circumstances it may relinquish the linguistic processing load to the dominant hemisphere. The next experiment was designed to choose between the two interpretations.

**EXPERIMENT 3**

The design of the experiment was similar to Experiment 1. The subject compared a visual test letter with a binaural set letter heard two seconds earlier, except that now he indicated whether the test letters had the same terminal phoneme as the set letter. If, for example, the set letter was “B” and the test was “G,” he responded “same” since both letters end in “ee”; if the test, however, was “M” he responded “different” since it does not end in “ee.” Successful performance in this task requires that the subject attend to linguistic features, namely, the phonemes in the letter’s name. Matching on the basis of pictorial characteristics would be useless unless the two letters were identical. Finally, to meet the objection raised in Experiment 2, the acoustic stimulus is presented 2 sec prior to the visual stimulus, allowing the minor hemisphere to examine the test stimulus for the appropriate linguistic features without having to simultaneously analyze the acoustic stimulus.

On one sixth of the trials for which the correct response was “same” the test letter and set letter were identical. This condition replicated Experiment 1 exactly and was included to see if subjects matching for terminal phonemes treat identical pairs, the letters of which share all features, pictorial and linguistic, the same as they do the letters of end-alike pairs which have only a terminal phoneme in common. This condition helps test the sufficiency of Kinsbourne’s (1970, 1973) attention model of perceptual asymmetry (see Discussion).

**METHOD**

**Subjects.** Sixteen right-handed students at the University of Pennsylvania participated in the experiment. Half responded with the left hand, half with the right.

**Procedure and stimuli.** The procedure and stimuli were identical to the one used in the previous experiments except for the following: (1) the subject responded “same” when the name of the letter he saw (test letter) ended in the same sound as the letter he heard (set letter) and “different” when they ended in a different sound. (2) The test letters comprising the positive set were B, D, G, T, V, Z, those comprising the negative set were F, L, M, N, S, X. The auditory set consisted of single letters drawn randomly from the positive set. All the letters in the positive set end in “ee” and all the letters in the negative set begin with “eh.” On one sixth of the positive trials the test and set letters were identical (identical condition). On the remaining five sixths of the trials, the test letters had only a terminal phoneme in common with the set letter (end-alike condition).

**RESULTS**

The results are summarized in Table 3 and aspects of them are highlighted in Fig. 4. The RTs for “same” judgements were analyzed by
TABLE 3
PHONEME COMPARISON TASK

<table>
<thead>
<tr>
<th></th>
<th>LVF</th>
<th>RVF</th>
<th>LVF</th>
<th>RVF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>E</td>
<td>I</td>
<td>E</td>
</tr>
<tr>
<td>Left hand</td>
<td>481 (10)</td>
<td>519 (16)</td>
<td>479 (10)</td>
<td>510 (26)</td>
</tr>
<tr>
<td>Right hand</td>
<td>491 (0)</td>
<td>535 (16)</td>
<td>507 (3)</td>
<td>525 (12)</td>
</tr>
</tbody>
</table>

Mean RT (msec) of correct responses averaged over subjects and broken down by response hand, visual field (LVF vs RVF), type of judgment (same vs different) and similarity of set-test pairs for "same" responses (identical (I) vs end-alike (E)). The number in parentheses next to the RT designates the number of errors in that condition.

A three-way analysis of variance, with response hand as the between factor and similarity (identical vs end-alike) and visual field as the within factor. The results of the analysis showed the following significant effects: similarity, identical RTs being 33 msec faster than end-alike RTs \[F (1,42) = 68.50; p < .001\], similarity by visual field interaction, identical RTs favoring the LVF, and end-alike RTs favoring the RVF \[F (1,42) = 4.10; p < .05\]. The end-alike and identical conditions were then analyzed separately. A two-way analysis of the end-alike condition, with response hand as the between and visual field as the within factor,
showed that there was a significant visual field effect, RTs being 10 msec shorter in the RVF \[F (1,15) = 7.06; \ p < .025\] and no significant response hand by visual field interaction. A similar analysis of the identical condition showed no significant main effects or interactions.

Although RTs for “different” judgements slightly favored the RVF, analysis of variance yielded no significant main effects or interactions.

**DISCUSSION**

Two main conclusions emerge from this experiment. The first is that perceptual asymmetries are determined, as all three experiments suggest, not by the stimulus material per se but by the cognitive processes that are emphasized in analyzing the information. The second is that the minor hemisphere of normal people displays little, if any, of the linguistic abilities that it might possess. The discussion that follows will elaborate on these conclusions.

*Cognitive Processes Determine Perceptual Asymmetries*

Although subjects were instructed to respond only to the presence or absence of a common terminal phoneme. RTs of “same” judgements to test letters in the identical condition were significantly shorter than RTs to the letters in the end-alike conditions. This suggests that different cognitive processes were used in the two conditions. In the identical condition, pictorial comparison of the test letter to a visual representation of the set letter leads to correct responses. In addition, the pictorial strategy has the advantage of eliminating the necessity of phonemically analyzing the name of the test letter, a linguistic process that the end-alike condition calls for. The results also show that the visual field that is favored depends on the process that is emphasized. Where a pictorial analysis is sufficient and more expedient, as in the identical condition, RTs will favor, though not significantly, the visual field projecting to the right hemisphere. This is consistent with the results of the first two experiments. In the end-alike condition, however, the emphasis on linguistic processes engages the left hemisphere and results in shorter RTs to test letters presented in the right visual field.

Similar results were obtained by Cohen (1972) and Geffen et al. (1972) in a modified Posner task. Subjects saw a pair of letters which were either identical, e.g., “aa” or “AA,” or which had the same name, e.g., “aA” and, in both conditions, were required to indicate whether the two letters had the same name. The pairs appeared in either the right or left visual field. The identical condition favored the left visual field whereas the name-alike condition favored the right visual field. Also, RTs to identical pairs were 80–130 msec shorter than to name-alike pairs. The relatively smaller difference of 33 msec between identical and
end-alike RTs in our experiment could be accounted for by the low probability of occurrence of identical pairs. Since RT is inversely proportional to the probability of an event, RTs were probably inflated for identical pairs and reduced for end-alike pairs.

The results of these experiments also provide evidence about whether linguistic and pictorial comparisons proceed serially or in parallel with each other. One possibility is that the comparisons are handled serially, such that the stimuli are first examined for identity on a pictorial dimension and are inspected for phonemic similarities only upon completion of the pictorial stage. If this were the case RTs would favor the left visual field even in the end-alike condition since the left visual field advantage associated with pictorial processes would be maintained over all the succeeding stages. That RTs favored opposite visual fields in the two conditions suggests that the phonemic and pictorial comparisons proceed in parallel with each other.

**Minor Hemisphere Performance on Linguistic Tasks**

A number of interpretations can account for the minor hemisphere’s inferior performance in the end-alike condition of the phoneme matching task. One interpretation is that when competing with the dominant hemisphere, the minor one does not engage in linguistic processes. Thus, all test letters must travel to the dominant side for phonemic comparison. Assuming that visual field differences in RT largely depend on the time it takes to transmit, receive, and interpret information transferred between hemispheres, then according to the above interpretation, RTs should favor the right visual field by identical amounts no matter which hand the subject uses to respond, i.e., no matter which hemisphere emits the response. If, however, each hemisphere independently processes linguistic information but the dominant does so more quickly than the minor, RTs will still favor the right visual field, but the difference would vary with response hand. For a dominant hand response, the time advantage gained by the accessibility of motor output pathways on the dominant side will be added to the linguistic processing advantage of the dominant hemisphere, whereas for a minor hand response the response initiation advantage rests with the minor hemisphere and so must be subtracted from the dominant’s advantage for processing linguistic information. In short, if the minor hemisphere displays the requisite linguistic skill, then a significant visual field by response hand interaction would be observed.

Examination of Table 3 shows that in the end-alike condition RTs favor the right visual field by equal amounts regardless of response hand. This favors the interpretation that in normal people the minor hemisphere does not contribute to the execution of tasks requiring linguistic
skill. Similar results were obtained in every reaction time study that has come to the author's attention (Geffen et al., 1971; Gross, 1972; Klatzky, 1970; Klatzky & Atkinson, 1972; Rizzolatti et al., 1971; Springer, 1971, 1972). A memory scanning study by Klatzky and Atkinson (1972) argues especially well against the notion that both hemispheres process linguistic information, but the minor is less efficient than the dominant. Their subjects indicated whether the name of a picture presented in the right or left visual field began with the same letter as one of the two to five letters they held in memory. If the minor hemisphere is merely less efficient than the dominant at processing linguistic information, then its performance relative to that of the dominant's should deteriorate with increases in the size of the memory set. This would be reflected in a corresponding increase in the size of the RT difference favoring the right visual field. The difference, however, remains constant over memory-set size regardless of the responding hand. Although the evidence from these studies minimize the importance of an efficiency interpretation of the hemispheres' performance on linguistic tasks, the possibility remains that the minor hemisphere processes linguistic information so slowly that a dominant hemisphere decision initiates a motor response on the minor or dominant side before a similar signal arrives from structures in the minor hemisphere. Even if this were true, it would still reinforce the conclusion that for all practical purposes linguistic behavior reflects only dominant hemisphere processes.

Before discussing the implications of this conclusion for models describing the localization of language, one last problem must be explored. Although studies using reaction times are consistent in that they each show visual field differences in the predicted direction, it is puzzling that these differences vary from study to study. The differences range from 2 to 50 msec and the variation as well as the absolute values are greater than expected if RT differences measured the time it took information to cross the corpus callosum. There are a number of ways of accounting for the variation. What is being measured is the time it takes to transmit, analyze, and encode information across the hemispheric pathways and not the time it takes a nerve impulse to cross the cerebral commissures. Assuming that stimulus information is degraded with transmission across the cerebral commissures and that the receiving hemisphere must clear up and interpret the transmitted signal, then it is likely that the more complex or faint the effective signal is, the greater the RT differences will be. By and large, this is the case. When measuring RTs for crossed and uncrossed sensory-motor projections to "simple" stimuli such as a flash of light or a touch on the skin, the differences are small and in the range of 2-20 msec (Blinkov and Arutyunova (and references in Russian), 1966; Bradshaw & Perriment, 1970; Efron, 1963;
Jeeves, 1969; Kerr, Mingay & Elithorn, 1963; Poffenberger, 1912). The only exception is a study by Filby and Gazzaniga (1970) who found differences of about 40 msec, but they required subjects to detect the presence or absence of a small dot. If, however, the attributes of the stimulus to which a subject must respond are complex, such as when letters, faces, pictures, slanted lines, speech, and random square matrices are used, then the differences obtained are in the range of 10–50 msec (Cohen, 1972; Geffen et al., 1971, 1972; Gibson et al., 1970; Gross, 1972; McKeever & Gill, 1972; Moscovitch, 1970, 1972; Rizzolatti et al., 1971; Springer, 1971, 1972; Umilta, Frost & Hyman, 1972).

Kinsbourne (1970, 1972) offered an alternative interpretation: RT differences to stimuli presented in the right or left sensory fields reflect attentional asymmetries about the midline rather than communication across hemispheric transmission lines. The more linguistically or pictorially complex the effective stimulus is, the more it selectively activates the left or right hemisphere, respectively, which in turn causes the subject to direct more of his attention to the sensory field contralateral to the activated hemisphere. As a result, stimuli presented to that field will be perceived better and with a shorter latency than when they are presented to the opposite field. The distinguishing feature of Kinsbourne's attention model is that it explains perceptual asymmetries on the basis of attentional biases induced by hemispheric activation prior to the presentation of the stimulus, whereas the traditional access model on which most of the theorizing in this paper is based claims that perceptual asymmetries result from post-stimulus effects; namely, the relative access which the effective stimulus trace has to the hemisphere specializing in its analysis. The attentional factors explain a variety of results that cannot be incorporated into the access model (see Kinsbourne, 1972) and undoubtedly contribute to some of the variance found in RT studies. The data from the present experiment, as well as that collected by other investigators, indicate that an activation-attention model is not sufficient to account for all the observed laterality effects—unless additional assumptions are made. Selective activation of one of the hemispheres could be eliminated by randomly presenting two types of stimulus material, one which engages left hemisphere processes and one which engages right hemisphere processes. According to the attention model, this should eliminate the corresponding perceptual asymmetries. This prediction was not borne out in the present study, or in Cohen's (1972) or in Geffen et al.'s (1972). In these experiments, the subject in-

4 Kinsbourne (1972) modified his attention model to account for post-stimulus effects. In its present form, however, there is little to distinguish the attention model from the access model regarding this explanation of post-stimulus effects.
dicated whether a pair of letters had the same name (Cohen and Geffen et al.) or had the same terminal phoneme (Moscovitch). RTs to pairs of letters that were identical and could be matched on the basis of physical characteristics favored the left visual field whereas RTs to pairs that had only a name or terminal phoneme in common favored the right visual field, despite the fact that the two conditions were presented randomly and so could not selectively prime one of the hemispheres prior to the presentation of the stimulus. Although pre-stimulus attentional factors may influence the magnitude of the differences obtained, they cannot account for these results as adequately as an access model.

GENERAL DISCUSSION

The paper began with the question “How does the normal minor hemisphere perform on linguistic tasks?” More specifically, does its performance reflect the linguistic skill it demonstrated in split-brain studies? These are questions concerning the functional organization of the normal cerebral hemispheres. The results of Experiments 2 and 3, as well as of similar experiments conducted by other investigators, suggest that the functional organization of the cerebral hemispheres of normal people is not the same as that of split-brain patients. This does not imply that if it were possible to examine each cerebral hemisphere in isolation in normal people it would reveal properties that are different from those of the split-brain hemispheres. Rather, it means that a new organization may emerge when the hemispheres interact with each other such that some properties or capacities are functional, are realized in behavior, while others, though present, may be obscured or inhibited. Thus, although the opportunity was present for the linguistic skills of the minor hemisphere to emerge, the linguistic behavior of normal people, as opposed to that of split-brain patients, reflected only the performance of

5 In the phoneme matching experiment the end-alike pair appeared five times as often as the identical one and, as a result, a slight “activation” effect was observed. RT differences to identical pairs were smaller than in Experiment 1, although they continued to favor the left visual field.

6 Levy (personal communication) claims that there is no inconsistency between the split-brain and normal data because the tasks chosen to test the linguistic skill of the normal minor hemisphere require phonological recoding of the stimulus. The split-brain minor hemisphere can semantically decode words to derive their meaning, but it cannot phonologically recode them in order to rhyme one word with another (Levy, 1973). This criticism, however, applies only to the phoneme matching task. It does not apply to Experiment 2 or to the name matching task of Cohen (1972) and Geffen et al. (1973). In those studies, subjects are asked whether two letters, such as “Aa,” sound alike, but rather whether they have the same semantic referrent—the name “A”—a task that involves the type of semantic decoding that the split-brain minor hemisphere should be able to execute. One sure way of determining the validity of this claim is to present these tasks to split-brain patients.
the dominant hemisphere. The subjects behaved "as if" the minor hemisphere did not possess any linguistic skill. Language, though possibly represented in the right hemisphere of normal people, appears to be functionally localized in the left.

This view of cerebral dominance forms one of the principal components of a model of cerebral organization. The model states that, allowing for individual differences, the right hemisphere's limited linguistic skills are present to an equal degree in all right-handed people, be they split-brained, aphasic, or normal. These skills, however, may be obscured and made nonfunctional by the linguistically dominant left hemisphere unless its influence over the right can be weakened or removed.

This model, termed the model of functional localization, was initially proposed to account for the apparent discrepancy between normal and split-brain data concerning the right hemisphere's linguistic performance (Moscovitch, 1973). In this it succeeds. Commissurotomy removes some of the major pathways via which the left hemisphere can influence the right, thereby permitting the right hemisphere's linguistic capacities to emerge. When the commissures are intact and the hemispheres healthy, as they are in normal people, the left hemisphere suppresses the right one's linguistic performance.

The model, however, also provides a conceptual framework for integrating various neurological phenomena that do not fit comfortably into any current theories. A detailed discussion of the model's application to these phenomena appeared elsewhere (Moscovitch, 1973). We will, therefore, restrict ourselves to listing some phenomena that may be better understood if they are seen as resulting from the release of right hemisphere language from left hemisphere control. These phenomena include (a) speech comprehension and production following dominant, left hemispherectomy in adulthood (Burklund, 1972; Crocket & Estridge, 1951; French, Johnson & Brown, 1955; Hillier, 1954; Smith, 1966; Smith and Burklund, 1966; Zollinger, 1935). (b) Lateralization of language in the right hemisphere following early injury to the language structures of the left (see Basser, 1962, for review). (c) The locus of aphasic speech in the healthy right hemisphere of some right-handed individuals following damage to the left hemisphere in adulthood (Kins-
bourne, 1971). (d) Verbal comprehension in people whose left hemisphere is anesthetized by intra-carotid injections of sodium amytal (Milner, 1967; Rossi & Rosadini, 1967; Wada & Rasmussen, 1960). (e) Reduction of the magnitude of right-ear superiority in verbal dichotic listening tests following left-hemisphere lesions (Oxbury & Oxbury, 1969; Schulhoff & Goodglass, 1969; but see Sparks, Goodglass & Nickel, 1970, for contradictory results). (f) Some recently reported findings, as yet not fully substantiated, may also merit investigation from the point of view of our model. These findings concern the relative sparing of ideographic, as opposed to phonological, writing systems in some kinds of aphasic syndromes (Sasanuma & Fujimura, 1971); the relative sparing of sign language, as compared to finger spelling and speech, in deaf people with left hemisphere damage (Critchley, 1938; Sarno, Swisher & Sarno, 1969, plus references, Tureen, Snolik & Tritt, 1951; for opposite results see Douglas & Richardson, 1959); the moderate, initial success some investigators have had in teaching global aphasics to communicate using an artificial, nonverbal language similar to that developed by Premack (1971) for chimpanzees (Velletri-Glass, Gazzaniga & Premack, 1973; Errol Baker, Aphasia Research Center, Boston, lecture delivered at L'Hôpital Hôtel-Dieu, Montreal).8

The findings mentioned in point (f) present special problems of interpretation. First, the particular forms of nonverbal communication that are spared may be dependent on processes that have little in common with those used in natural language. Second, even if nonverbal and verbal forms of communication share some common processes, it may be that the nonverbal form is simpler in the sense that the link between symbol and meaning is more direct than it is for speech and for phonological writing systems. Consequently, some nonverbal communication may be spared not because it is mediated by the right hemisphere, but because its relative simplicity allows it to be mediated by the remaining healthy tissue of the damaged left hemisphere. These considerations make the investigation of nonverbal communication particularly interesting both for the linguist and the neuropsychologist.

Other language-related disturbances, such as global aphasia, word-blindness, and word-deafness in individuals with healthy, normal minor hemispheres may occur if the left hemisphere continues to suppress the verbal activity of the right. As mentioned in the introduction, others (Sperry et al., 1969; Milner, 1970) offered a similar explanation but they considered the pathology on the dominant side as the cause of the minor hemisphere's poor linguistic performance. According to our model, the

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8 A finding related to those mentioned in point (f) concerns the selective loss of the ability to read abstract words while the ability to read concrete words is retained (Alan Baddeley, Colloquium presented at the University of Toronto, November, 1974).
pathological situation in which a malfunctioning dominant hemisphere interferes with the activity of a healthy minor one is merely an unfortunate extension of the normal condition.

Finally, the model of functional localization may lead to a clearer understanding of the development of lateralization of function. This matter will be discussed in greater detail because it illuminates some of the points mentioned earlier and because it underscores the potential the model has for directing future research.

Anatomical asymmetries between the hemispheres have been found in infants suggesting that the predisposition for the development of left hemisphere linguistic dominance may already be present at birth. It is possible that during the first 5 or 10 years of life, the dominant hemisphere magnifies this initial advantage in two ways: (1) by acquiring language faster than the minor side (2) by suppressing the verbal behavior of the minor side in proportion to its (the dominant's) rapidly accumulating linguistic skills. Some of the verbal competence that the minor hemisphere possessed in childhood remains. Some language functions, however, may deteriorate through disuse while others may perhaps be lost as a result of the differentiation of potentially linguistic structures into those serving nonlinguistic functions. Pathology of the dominant hemisphere may reduce its ability to acquire language and to control the minor one, leaving the minor hemisphere relatively free to develop and practice its verbal skills which may result in the minor hemisphere assuming the dominant role.

If true, this account predicts that early damage to, or absence of, interhemispheric pathways should also lead to greater language development on the minor side. There have been a number of recent reports of laterality tests on patients with callosal agenesis (Bryden & Zurif, 1970; Ettlinger, Blakemore, Milner & Wilson, 1972; Sperry, 1970). The results of these tests are difficult to interpret because there are often other cerebral abnormalities accompanying this disorder. Nonetheless, it is interesting to note that language functions are imperfectly lateralized in this population, suggesting that both hemispheres comprehend language and may, perhaps, even speak (Sperry, 1970). Reports of more elaborate...
tests determining whether language functions are represented equally in
both hemispheres are just beginning to appear (Saul & Scott, 1973).

It was suggested earlier that lateralization of language to the left hemi-
sphere may lead to the differentiation of potentially linguistic structures
on the right into those serving nonlinguistic functions. This leads to the
prediction that the lateralization of language on the left precedes the lat-
eralization of nonlinguistic functions on the right. It also predicts, as
some investigators have already found (Levy, 1973), that if language
develops on the right it may take over some structures that would nor-
mently mediate nonverbal function and, thereby, lower the person’s per-
formance on nonverbal tasks.

There is another approach to the problem of lateralization of function.
Rather than speculate, as we did, about the processes whereby some un-
determined differences between the two hemispheres lead to the lat-
eralization of function, one can inquire into the nature of those dif-
ferences. What special properties does the left hemisphere have which
cause it to become linguistically dominant? Opinion on this matter has
been divided. One group believes, simply, that language is lateralized in
the left hemisphere because it is rich in the special purpose mechanisms
necessary to deal specifically with phonological and syntactic informa-
tion that is peculiar to natural speech (Liberman, 1974). A second group
sees the problem in much broader terms. To them, language, be it con-
voyed by speech, gestures, or pictorial symbols, is the product of highly
generalized cognitive operations. Because these operations are the spe-
cial province of the left hemisphere, language is lateralized to that side.
The right hemisphere, on the other hand, operates in a mode that is
incompatible with the processes necessary for language. As yet, the
descriptions of these two opposing cognitive modes is rather vague. The
right hemisphere has been conceived as a “concrete, spatial synthesizer”
that perceives information as a “meaningful Gestalt” (Levy, 1973) and
can be expected to process information in parallel (Cohen, 1973). Its
mode of thinking has been described as appositional and creative
(Bogen, 1969b; Bogen & Bogen, 1969), nonlinear and intuitive (Orn-
stein, 1972). Such cognitive traits, it is claimed, are incompatible with
the rational, abstract, propositional, temporally-ordered and, therefore,
linear and serial mode of thinking which characterizes the left hemi-
sphere and on which language depends. These notions are similar in
spirit, and sometimes in content, to those of Jackson (1878), Head
(1926), and Goldstein (1948) who believed aphasia resulted not only
from the impairment of mechanisms that evolved to deal specifically
with speech, but also from a deficiency in “symbolic formulation and
expression” and abstract reasoning. By examining the language that is
presumed to be mediated by the right hemisphere, one may be able to
decide between these two points of view. If the former is correct, right hemisphere language should merely be an impoverished version of that of the left. If the latter, more general view, is correct, right hemisphere language should differ qualitatively from that of the left because the underlying properties of the two languages, their rules, not their external symbols, should reflect the cognitive operations peculiar to the two hemispheres. Current research on split-brain and hemispherectomized patients, as well as on aphasic patients being taught to communicate in artificial languages, should indicate if there is anything unique about right hemisphere language.

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