Hemispheric specialization for processing of visually presented verbal and spatial stimuli*,**

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Two "same-different" reaction time experiments, analogous in task demands made on the S, were designed to test laterality differences in perception. Ten normal right-handed Ss performed a verbal task in which they decided whether or not two three-letter words belonged to the same conceptual class. Ten different Ss performed a spatial task in which they decided whether two 16-cell matrices with 3 blackened cells were identical. Reaction times were found to be sensitive to laterality differences in perception. Verbal stimuli were processed faster when presented in the right visual field, and thus projected directly to the left cerebral hemisphere; spatial stimuli were processed faster when presented in the left visual field, and thus projected directly to the right cerebral hemisphere. These results were analyzed in terms of implications regarding hemispheric asymmetries for processing of verbal and spatial material and the nature of interhemispheric transfer of information.

A large body of literature, derived from a number of diverse research methodologies, lends support to the idea of differential specialization of the two cerebral hemispheres in man. One such apparent division of function, suggested by studies of patients with asymmetric cerebral damage (e.g., Milner, 1968) or with surgical disconnection of the cerebral hemispheres (Gazzaniga, Bogen, & Sperry, 1965; Gazzaniga & Sperry, 1967), is that of separation of processing of linguistic and nonlinguistic information. Perceptual laterality studies in both the auditory and visual modalities on normal Ss have also supported the conclusion that linguistic processing and/or output appears to be primarily localized in the left cerebral hemisphere, while the right hemisphere is specialized for nonlinguistic (in the visual modality, spatial) processing. This cerebral dominance conformation is especially predominant in right-handed Ss, the overwhelming majority of whom have

speech output centers in the left cerebral hemisphere.

A number of previous laterality studies in normal Ss have used a measure of percent correct report. In the auditory modality, for example, Kimura (1961) found that digits presented to the right ear were identified more accurately than those presented to the left ear in a dichotic presentation. Conversely, Kimura (1964) found that recognition with the left ear was superior when the task was nonverbal.

In the visual modality, laterality studies have utilized stimuli presented to either the left or the right visual hemifield in order to produce cortically lateralized presentations. The structure of the human visual system is such that the initial projection of stimuli presented to the right of fixation (RVF) is solely to the left cerebral hemisphere, while that of stimuli presented to the left of fixation (LVF) is to the right cortex. Bryden (1965) and Kimura (1966), for example, have reported a right-field advantage for the perception of verbal material. Conversely, Kimura (1969) found that location of a dot in space was superior in the left visual field, while Schell and Satz (1970) found a left-field superiority in recognition of a previously shown block design.

If the perceptual asymmetries found in visual presentations are interpreted as being indicative of a hemispheric localization of some part of the perception of or response to these stimuli, two different processing/output alternatives are suggested. It may be that all or some necessary part of verbal processing must take place in the left hemisphere (at least in right-handed Ss), such that

those verbal stimuli presented to the RVF have the advantage of more direct access to the appropriate processing center. Alternatively, verbal stimuli may be processed in the right hemisphere, but (1) the processing may be slower and not as accurate, and/or (2) the verbal response must always be directed by the left hemisphere, permitting possible information loss during the callosal transmission preceding output. For spatial stimuli, direct presentation to the right hemisphere should yield a processing advantage. Such an advantage would be expected to be decreased (if the left hemisphere were also capable of doing some spatial processing) if verbal response were required.

Recently, several studies utilizing a reaction time (RT) measure of hemispheric asymmetries were undertaken. In the auditory modality, Springer (1971a) found that motor RT to right ear verbal targets in a dichotic situation was shorter than that to left ear targets. In the visual modality, a number of studies (Filbey & Gazzaniga, 1969; Gibson, Filbey, & Gazzaniga, 1970; Klatzky, 1970; Moscovitch & Catlin, 1970) supported the notion that hemispheric specialization of function for the linguistic vs spatial processing modes is reflected in RT differences between the visual hemifields.

It was the object of the present experiments to utilize a RT measure as a potentially more sensitive index of dominance within an individual than is percent correct report, as well as to provide more extensive data about the nature of the information flow between hemispheres than has previously been possible. Just as the transfer of information across the callosum for processing and/or output may yield a performance decrement in accuracy, it could also yield a slower RT, attributable either to callosal crossing time or to information loss. By manipulating stimulus parameters (linguistic vs spatial input) and response parameters (verbal vs motor response, inter- vs intrahemispheric sensory-motor connections by means of visual field and responding hand combinations), it should be possible to study the laterality effect in terms of both processing and output functions.

In the present experiments, both stimulus and response parameters were manipulated. Two experiments, one a "verbal" task and one a "spatial" task, were performed, which made analogous task (decision and response) demands upon the S. In each, S performed a "same"- "different" RT task. In the verbal task, S decided whether two words presented simultaneously were in the same

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category (both animals or both parts of the body) or in different categories. In the spatial task, S decided whether two 16-cell matrices with 3 cells blackened were the same (all 3 black cells in register) or different. In each experiment, each S gave verbal responses, as well as manual responses with both right and left hands.

EXPERIMENT 1: VERBAL TASK

In Experiment 1, Ss decided whether two three-letter word stimuli were in the same category or in different categories.

Method

Subjects. The Ss were four female and six male members of the Stanford community between the ages of 18 and 26, who were paid \$1.75 per session. All Ss met the three selection criteria of (1) having normal or corrected vision of at least 20/22 in each eye, as measured with a Keystone Ophthalmic Telebinocular, with an acuity difference no greater than one-half step between eyes (e.g., 20/20 and 20/20—), and having at least 100% stereopsis on the Navy eye-screening test scale, (2) being right-handed as defined by self-label and by the hand with which they wrote when filling out the experimental questionnaire, and (3) having no history of neurological disorder or speech defect. The 10 Ss scored an average of 22.7 on the Crovitz and Zener (1962) handedness scale.

Stimuli. Two sets of eight three-letter words were prepared, one set of animals and one of parts of the body. Three-letter words were chosen in order to preclude any potential scanning effects [see White (1969) for a discussion of the laterality literature oriented toward this explanation of field differences]. Studies by Coltheart and Merikle (1970), Krueger (1970), and Smith and Haviland (1972) indicate that such words are perceived as units rather than scanned from left to right. As an additional safeguard, the response was dependent upon a "completed" perception of both words, since it was necessary to compare their "categories." The eight animal words were: ape, cat, cow, dog, elk, hen, pig, rat. The eight parts of the body words were: arm, ear, eye, hip, jaw, leg, rib, toe.

Using these words, 64 stimulus configurations were designed. Each was composed of two different words, one above the other, drawn either from the same category or from different categories. Thirty-two "same" units were designed; 16 "same" units were drawn from the "animal" group and 16 from the "body" group. Each word in each group appeared in four "same" pairs,

twice on top and twice on the bottom. Thirty-two "different" units were made up, half with an animal word on top, half with a "body" word on top. Each word in each group appeared in four "different" pairs, twice on top and twice on the bottom. Each of the 64 stimulus configurations appeared once to the left and once to the right of fixation, making a total of 128 stimulus configurations. These 128 stimuli were divided into four blocks of 32 stimuli; both the right- and left-field presentation of a stimulus appeared within a block, randomized with the constraint that no more than four consecutive correct responses were identical. Ss received these four blocks in different assigned orders in each session, with blocks presented in reverse order one-half of the time.

The stimuli were made with black 48-point Helvetica Medium Letraset letters ($\frac{1}{4}$ in. high, subtending about 1 deg 14 min of visual angle at a viewing distance of 23 in.) mounted on white construction paper. The two words appeared, respectively, at 1 mm above and below the fixation dot, which appeared in the preexposure field, centered 37 mm to the left or right of the fixation dot (3 deg 34 min of visual angle). The words were from 30 to 34 mm in length, subtending from 2 deg 58 min to 3 deg 16 min of visual angle. Therefore, the closest approach to the fixation point was about 2 deg.

Procedure. Experimental stimuli were exposed in a Gerbrands two-field mirror tachistoscope. Centered in one field was a black fixation dot; this field was always on except when test stimuli were being presented, and S was instructed to maintain fixation on the center dot. The luminance of the fixation field was 5.9 fL; that of the test field was 6.2 fL. The E signaled the onset of a test by saying "now." Stimulus duration was 150 msec, to preclude shifts in fixation.

Reaction time was measured to the nearest millisecond by an electronic decade counter (Hunter KlocKounter), which was activated simultaneously with stimulus onset and was stopped by S's response. In verbal response sessions, S spoke into a microphone that activated a voice relay (Trans-Vox Model Vox-1) that stopped the clock; half the Ss responded "at" to the same stimuli and "it" to different stimuli, while half did the reverse. In motor response sessions, S pushed a lever grasped between the thumb and forefinger up or down, which stopped the clock by means of a mechanical closing. Those Ss who verbalized "at" for "same" pushed the lever down for "same" and up for "different" stimuli; those who verbalized "it" for "same" did the reverse.

Each S served in a practice session, during which he became familiar with the stimuli and methods of responding. Each then served in eight experimental sessions, consisting of six practice trials followed by 128 test stimuli. The Ss were instructed to respond as quickly as possible, consistent with accuracy. Stimuli on which errors were made were reinserted into the stimulus sequence 2-5 presentations later. Order of nature of response (verbal or manual) for sessions was counterbalanced within a S and across Ss. In the motor sessions, right and left hands were used in alternate blocks; the alternation was counterbalanced within a S and across Ss.

Results

Mean RTs for each visual field (right or left), response mode (verbal, right hand, or left hand), and response ("same" or "different") were computed for each session. These means excluded error or repeat trials; however, the error rate for each S was low and did not seem to differ with regard to visual field of the presentation. The mean error rate was 4.5%; the range over Ss was 1.2% to 11.5%. In addition, extreme RTs were dropped. (The drop rule used entailed examining the distribution of RTs for all "same" stimuli and all "different" stimuli within a session separately. If a 200-msec gap was found in the distribution, numbers that were separated from the main body of the data by the gap were dropped. Number of dropped stimuli did not differ with respect to side of presentation.) The means so obtained for each session were averaged across sessions, yielding 12 means for each S. The pattern of means obtained averaged across Ss is shown in Table 1.

An analysis of variance of these mean RTs (Field by Response Mode by Response, within Ss) was performed. The analysis of variance showed that RT for this verbal processing task was faster for the RVF than for the LVF, 1,063.2 and 1,093.9 msec, respectively [$F(1,9) = 11.56$; $p < .01$]. All of the 10 Ss showed faster RT to RVF stimuli, a "right-field effect."

Verbal response was slower than that of either the right or left hand, 1,145.0 msec vs 1,048.5 and 1,042.2 msec, respectively [$F(2,18) = 11.32$; $p < .001$], while RTs for right and left hand did not differ significantly [$t(9) = 1.005$, n.s.]. "Same" responses were faster than "different" responses, 1,042.5 and 1,114.7 msec, respectively [$F(1,9) = 15.36$; $p < .01$]. The Response Mode by Response interaction was also significant

[$F(2,18) = 4.01$; $p < .05$]; the "different" response took relatively longer than "same" for the motor response modes than for the verbal (93 msec vs 31 msec). This difference, however, is significant at only the .05 level, one-tailed, and it does not appear to yield any information relevant to hemispheric specialization.

No other interactions were significant. The Field by Response Mode interaction failed to reach significance, indicating no differential field effect depending upon presumed hemispheric locus of response (for example, if the RT difference for the right vs the left visual field had been greater for the verbal response and right-hand response than for the left-hand response, a statistically significant difference would have been obtained). A *t* test performed on RT differences for RVF vs LVF using motor responses alone (motor response field difference) showed no differential field effect for the right vs left hand [$t(9) = .13$, n.s.]. A *t* test between combined right-hand and left-hand motor field differences and verbal field differences was also nonsignificant [$t(9) = .29$, n.s.], indicating that the right-field RT advantage is the same with both motor and verbal responses. The Field by Response interaction also failed to reach significance, indicating that the right-field superiority is maintained regardless of whether S is making a "same" or a "different" response.

Because the traditional measure of the laterality effect has been difference in percent correct report between fields, several analyses regarding error rate for different conditions were performed. Percent errors summed across Ss for each condition is shown in Table 2. A *t* test for correlated means was performed on the differences between the number of errors made in the RVF vs the LVF for each S (mean error rate of 4.1% in the RVF vs 5% in the LVF). This difference between fields did not reach significance [$t(9) = 1.86$, n.s.]. In addition, chi-square tests showed no significant difference in errors,

summed across Ss, between the hand by field combinations of the motor response sessions, [$\chi^2(3) = 5.84$, n.s.] or between the response mode by field combinations, summing across all sessions [$\chi^2(3) = 4.77$, n.s.]. The present results indicate that evidence for hemispheric asymmetry, as indicated by RT differences, may be found even under conditions in which no significant difference in error rate is found. This suggests that RT may prove to be a more sensitive measure of hemispheric specialization than is the more traditional percent correct measure.

EXPERIMENT 2: SPATIAL TASK

In this experiment, as in the verbal experiment, Ss made a "same"- "different" decision regarding the stimulus presentation. In this case, the decision was whether two 16-cell matrices with 3 blackened cells were identical (all 3 blackened cells in correspondence) or not ("different"). It was felt that this task would be appropriate for the spatial condition in part because Sekuler and Abrams (1968) reported that Ss presented with a similar task seemed to perform a "template match." In an effort to emphasize the spatial "Gestalt" nature of the task, Ss were instructed to "try to take into account the total stimulus configuration" when making their responses.

Method

Subjects. The Ss were five male and five female members of the Stanford community between the ages of 18 and 27, who were paid \$1.75 per session. All Ss met the selection criteria (vision, right-handedness, and no speech defects) described in Experiment 1. The 10 Ss scored an average of 20.8 on the Crovitz and Zener (1962) handedness scale. None of the Ss had served in Experiment 1.

Stimuli. Three groups of four 16-cell black-and-white matrices with 3 cells blackened were designed. Group 1 matrices differed from each other by one black cell and had two black cells in common; Group 2

Table 2
Percent Errors for Each Field by Response Mode Combination: Verbal Task

Response Mode	Field	
	Right (Percent)	Left (Percent)
Right Hand	4.4	5.2
Left Hand	3.3	4.6
Verbal	4.4	5.0

matrices differed from each other by two black cells and had one black cell in common; Group 3 matrices had no black cells in common. The matrices used are shown in Fig. 1.

Using the 12 matrices, 48 stimulus configurations, 12 "same" and 36 "different," were designed. Each was composed of either two of the same matrix, one above the other ("same"), or of two matrices from the same group, one above the other ("different"). Each of the 12 possible "same" configurations appeared three times to both the right and left of fixation. Each matrix in each group was paired with all other matrices in that group in both the top and bottom position to form the "different" stimuli. Each different configuration appeared once to both the left and right of fixation. The 144 stimulus presentations were divided into four blocks of 36 stimuli; both the right- and left-field presentations of a stimulus appeared within a block. The assigned block order for each session for each S in Experiment 2 matched an order assigned to an S in Experiment 1.

Multiple copies of the 12 matrices were made by an offset printing process. The 144 stimuli were made by cutting out individual matrices and affixing them to white construction paper. The matrices appeared, respectively, 1 mm above and below a fixation dot that appeared in the preexposure field, centered 36 mm to the left or right of the fixation dot (3 deg 28 min at a viewing distance of 23 in.). The matrices were $1\frac{1}{4} \times 1\frac{1}{4}$ in., subtending a visual angle of 3 deg 8 min $\times$ 3 deg 8 min at a viewing distance of 23 in. The closest approach to the fixation dot was, therefore, approximately 2 deg.

Procedure. The apparatus and experimental procedure were identical to those of Experiment 1. Each S served in eight sessions, during which RT measures for the 144 test stimuli were obtained. For each S, the sequence of the nature of response used in a given session was matched to a sequence assigned to an S in Experiment 1.

Results

Mean RTs for each visual field (right or left), response mode (verbal, right

Table 1
Overall Mean Reaction Time (Milliseconds) for Each Field by Response Mode by Response Combination: Verbal Task

Response Mode	Response	Field		
		Right	Left	
Right Hand	Same	981.6	1023.8	1048.5
	Different	1081.1	1107.5	
Left Hand	Same	979.6	1011.1	1042.2
	Different	1068.2	1110.1	
Verbal	Same	1115.8	1142.8	1145.0
	Different	1153.2	1168.1	
		1063.2	1093.9

Fig. 1. Matrices used in spatial task.

hand, or left hand), and response ("same" or "different") were computed for each session for each S. As for Experiment 1, these means excluded error trials. Mean error rate was 5.3%; the range over Ss was 2.9% to 10.1%. Extreme RTs were dropped according to the same criterion used in Experiment 1. Means so obtained for each session were averaged across sessions, yielding 12 means for each S. The pattern of means obtained averaged across Ss is shown in Table 3.

An analysis of variance of these mean RTs (Field by Response Mode by Response, within Ss) was performed. The analysis of variance showed that RT for this spatial task was faster for the LVF than for the RVF, 909.9 and 928.2 msec, respectively [F(1,9) = 16.83; $p < .01$]. All of the 10 Ss showed faster RT to LVF stimuli, a "left-field effect."

Verbal response was slower than that of either the right or the left hand, 1,020.9 msec vs 866.6 and 869.7 msec, respectively [F(2,18) = 15.98; $p < .001$], while RTs for right and left hand did not

differ significantly [$t(9) = .27$, n.s.]. As in the verbal task, "same" responses were faster than "different" responses, 887.6 msec and 950.5 msec, respectively [F(1,9) = 6.98; $p < .05$].

No interactions were significant. The Field by Response Mode interaction failed to reach significance, indicating no differential field effect depending upon presumed hemispheric locus of response (e.g., if verbal and right-hand response behaved similarly and showed a smaller left-field effect than did left-hand response). As with the right-field advantage found in

Experiment 1, a t test indicated no difference in the magnitude of the left-field advantage obtained with right vs left hand [$t(9) = .83$, n.s.] or for verbal vs motor response [$t(9) = 1.13$, n.s.]. These data, comparable to the results obtained in the verbal experiment, support the hypothesis that at least some part of all spatial processing must take place in the right cerebral hemisphere, since the locus of output did not affect the magnitude of the field difference obtained. The Field by Response interaction also failed to reach significance, indicating that the left-field superiority is maintained regardless of whether S is making a "same" or a "different" response.

Several analyses regarding error rate for different conditions were performed. Percent errors summed across Ss for each condition are shown in Table 4. A t test for correlated means was performed on the difference between the number of errors made in the LVF vs RVF for each S (mean error rate of 5.3% in the LVF vs 5.5% in the RVF). This difference between fields did not reach significance [$t(9) = .47$, n.s.].

In addition, as for Experiment 1, chi-square tests showed no significant differences in errors summed across Ss for right and left visual fields and right and left hands [$\chi^2(3) = 1.12$, n.s.] or for right and left visual fields and verbal and motor response [$\chi^2(3) = 2.70$, n.s.]. As in Experiment 1, then, evidence for hemispheric asymmetry, as indicated by RT, was found in the absence of significant differences in error rate.

A secondary analysis was performed in order to examine the notion (Levy, 1969) that it is the Gestalt nature of the task for which the right hemisphere is specialized. If this were so, the number of blackened cells in register should not significantly affect the RT for the "same"-"different" judgment, since simultaneous checking of all cells would be made in a "template match." The average RT for each type of "different" judgment (zero, one, or two blackened cells in register) and for the "same" judgment

Table 3
Overall Mean Reaction Time (Milliseconds) for Each Field by Response Mode by Response Combination: Spatial Task

Response Mode	Response	Field		
		Right	Left	
Right Hand	Same	843.0	827.1	866.6
	Different	910.5	885.8	
Left Hand	Same	837.7	830.6	869.7
	Different	912.4	898.1	
Verbal	Same	1007.0	980.4	1020.9
	Different	1058.8	1037.4	
		928.2	909.9	

was obtained for each visual field for each session for each S. These scores were then averaged across sessions. The relationship of RT (averaged over 10 Ss) to number of cells in register for each visual field is shown in Fig. 2.

As was indicated by the "same"- "different" dichotomy in the analysis of variance for this experiment, "same" RT was less than any of the "different" RTs. The slope of the line for the "different" RTs was fitted by the least-squares method for each S for each visual field. A significant linear component was found for increasing RT with increasing number of cells in register for both the right visual field [slope = 51.5; $t(9) = 6.20$; $p < .001$] and for the left visual field [slope = 47.4; $t(9) = 4.6$; $p < .01$]. The slopes for right vs left visual fields, compared with a correlated means t test, were not significantly different [$t(9) = .95$, n.s.]. These results are not in accord with those of Sekuler and Abrams (1968), since they did not obtain any "same"- "different" dichotomy, but obtained instead a linear trend (with small slope) for increasing RT with increasing number of cells in register, regardless of whether the appropriate response was "same" or "different." The results of the present analyses do not suggest the employment of a solely Gestalt processor.

Comparison of Verbal and Spatial Tasks

In order to determine whether the magnitudes of the field differences obtained were the same for both the verbal and spatial tasks, the average of the motor response (average of right and left hands) and verbal response field differences was obtained for each S in each experiment. A two-sample t test was performed on the absolute magnitude of field differences for the two tasks (28.3 msec for the verbal task, 19.8 msec for the spatial task). The absolute magnitude of the field difference did not differ significantly according to the nature of the task [$t(18) = 1.02$, n.s.].

In general, then, the magnitude of field differences obtained for each task was the same for verbal or manual response modes and "same" or "different" responses. The field

Table 4
Percent Errors for Each Field by Response Mode Combination: Spatial Task

Response Mode	Field	
	Right (Percent)	Left (Percent)
Right Hand	5.6	4.8
Left Hand	5.6	5.1
Verbal	5.4	5.6

Fig. 2. Reaction time (spatial task) for each visual hemifield as a function of number of blackened cells in register.

differences for the two tasks were in opposite directions (right-field superiority for the verbal task, left-field superiority for the spatial task), but were not significantly different in absolute magnitude. The two field differences, then, can reasonably be attributed to the same underlying phenomenon. A summary of the RTs obtained in the two experiments is shown in Table 5.

DISCUSSION

It might be asked whether the between-field RT differences obtained in this study are consistent with measures of callosal transmission time. The magnitude of field differences obtained in these experiments is consistent with some electrophysiological studies (Bremer, 1958; Grafstein, 1959; Teitelbaum, Sharpless, & Byck, 1968), which have shown that excitation originating exclusively in one hemisphere takes approximately 10 msec (primary positive wave) to 35 msec (secondary negative wave) to cross the callosum and its related synapses to the opposite hemisphere. This consistency would suggest that differences in RT for verbal vs spatial tasks for the two visual hemifields are attributable to the extra time required for a callosal transmission of stimulus information for processing. Other behavioral studies (Poffenberger, 1912; Berlucchi, Heron, Hyman, Rizzolatti, & Umiltà, 1971), however, indicated a much shorter callosal transmission time,

more consistent with the time required for a few synaptic transmissions. Such studies measured the difference in RT for simple visual stimuli (which could, presumably, be processed in either hemisphere), which were presented to the visual field ipsilateral (uncrossed connections) or contralateral (crossed connections) to the responding hand. RT differences on the order of 2-6 msec were found. The magnitude of RT differences obtained in the present experiment (an average of 24 msec) is not consistent with these measures of simple callosal transmission time.

Even if it were possible for the obtained latency differences to be consistent with all previous measures of callosal transmission time, however, it is necessary to account for the data regarding inferior recognition of verbal material in the LVF (Kimura, 1966; Bryden, 1965) and of spatial material in the RVF (Kimura, 1969; Schell & Satz, 1970). A required callosal transmission would cause longer latency of response, but, if the transmission were complete in detail, should not cause inferior performance for stimuli initially projected to the nonspecialized hemisphere. If, however, the corpus callosum had a limited channel capacity, this inferior performance would be explained, since information loss during transmission could decrease accuracy. This effect would be most pronounced in those situations where stimulus information was already minimal, as when stimuli

Table 5
Overall Mean Reaction Time (Milliseconds): Comparison of Verbal and Spatial Tasks

Task	Field	Response Mode		Field by Task Means
		Motor*	Verbal	
Verbal	Right	1027.6	1134.5	1081.0
	Left	1063.1	1155.5	1109.3
	Verbal Means	1045.3	1145.0	1095.2
Spatial	Right	875.9	1032.9	954.4
	Left	860.4	1008.9	934.6
	Spatial Means	868.2	1020.9	944.5

*Mean of the right and left hand

are presented at very short durations. Such a callosal transmission explanation, then, would explain both differences in error rate and latency differences between visual hemifields.

Such an inherent limitation in channel capacity is indicated by behavioral (Myers, 1962) and electrophysiological (Berlucchi & Rizzolatti, 1968) studies in cats. These experiments suggest that the effect of stimuli projected via the corpus callosum is not identical to that of the same stimuli projected to a given hemisphere via geniculocortical pathways.

Furthermore, Buchsbaum and Fedio (1970) report a greater stability in two responses to the same stimulus have a higher correlation with each other than evoked response activity in humans to stimuli projected via the direct visual pathways to each hemisphere than to stimuli taking secondary, indirect pathways. It seems very likely, therefore, that the latency differences observed in the present tasks are attributable to both callosal transmission time and to increased latency of response accompanying uncertainty attendant upon a "degenerate" stimulus transmission.¹

Geffen et al (1971) have suggested that processing of a given stimulus may be performed, although more slowly, by the hemisphere which is not specialized for that stimulus type. They found a shorter RT in the LVF for perception of faces with a motor response, but not with a verbal response. Geffen et al interpreted these data as indicative of a right-hemisphere superiority (quickness) for this spatial task, which was "cancelled" because of the necessity for verbal response (initiated solely by the left hemisphere). The present experiment yielded a right-hemisphere superiority for the spatial task regardless of whether verbal or manual response was required; the magnitude of this field difference did not differ significantly for verbal vs motor response. The data of the present experiment are not in accord with Geffen's conclusion that the nonspatial hemisphere can perform spatial processing, although more

slowly; rather, they indicate that all or at least some part of all spatial processing must take place in the right hemisphere. It is possible that the matrix task in the present experiment was a more difficult spatial task than the "faces" task or was more strictly dependent upon spatial cues, such that processing had to take place in the right hemisphere, while processing of the faces might take place in the left hemisphere as well.

The present data can be most parsimoniously accounted for by models that postulate that all or part of the processing of verbal stimuli must take place in the left cerebral hemisphere, while all or part of the processing of spatial stimuli must take place in the right cerebral hemisphere. It might then be expected that, in accordance with the results of Bradshaw and Perriment (1970), the right hand would be faster for a verbal task (left hemisphere), while the left hand would be faster for a spatial task (right hemisphere). (This "hand effect" hypothesis is distinct from a Hand by Field interaction, the implications of which have been previously discussed.) It is interesting, however, to note that the differences in RTs for the two hands in the present experiment, although nonsignificant, were exactly the opposite of that proposed by a model that assumes motor output directed exclusively from the hemisphere dominant for a given task (in order to avoid an additional callosal transmission for output). The left hand was faster for the verbal task, while the right hand was faster for the spatial task. The total number of errors for all Ss for each hand in each task were in the same direction as the reaction time differences, although error differences are also not significant. Rizzolatti et al (1971) reported RT differences and error rate differences for the two hands that are in the same direction as those in the present experiment, although these authors did not discuss this trend. Klatzky and Atkinson (1971) found a general left-hand superiority in a RT task, which was lessened if the necessary processing was spatial rather

than verbal. Although none of the results described are statistically significant, consistent results such as these might suggest that motor output (possibly for both hands) is being directed by the hemisphere that is not performing the processing, but is, instead, somehow monitoring for the result (a time-sharing system, of sorts).

The results of this experiment also provide some suggestions regarding the nature of a "spatial" task. Rizzolatti et al (1971) mentioned that right-hemisphere superiority for the recognition of faces (their spatial task) might be related to some peculiarity of physiognomy as a visual pattern. In the present experiment, a right-hemisphere superiority was found for processing of complex, nonface spatial stimuli, suggesting that it is the necessary spatial coding (nonlinguistic nature of the task) that is the relevant factor.

Levy (1969) has suggested that the right hemisphere may be specialized for Gestalt processing. Bradshaw and Wallace (1971), however, found evidence for a serial model for the processing of faces, and facial stimuli have been shown to yield a right-hemisphere advantage. Similarly, in the present spatial task, no evidence was found to support the hypothesis of the employment of a Gestalt processor, even though, under other experimental conditions (Sekuler & Abrams, 1968), a similar matrices task was found to be Gestalt in nature. (It should be noted, however, that Sekuler and Abrams got better "Gestalt" results with two-cell stimuli than with four-cell stimuli. It may be that the three-cell stimuli of the present experiment are too difficult to be processed in an entirely Gestalt manner.) In the present experiment, the highly significant linear trend for increasing RT with increasing number of cells in register for "different" stimuli is not suggestive of a Gestalt process. In spite of mitigating factors that might serve to explain why processing was not Gestalt in nature in the present matrices task, it is still valid to say that the data obtained provide no evidence to indicate that right-hemisphere superiority must be dependent upon the Gestalt nature of the task. Rather, it seems sufficient that processing for the task utilizes spatial cues. It is, however, possible that further experiments will indicate that Gestalt tasks produce a more pronounced laterality effect.

The results of the present experiment, then, definitely support a model of hemispheric specialization for processing (as distinct from just output), the left hemisphere specialized for verbal tasks and the right hemisphere specialized for spatial

tasks. The results also indicate no significant effect of lateralization of right-hand vs left-hand motor output, but there are some aspects of the data that suggest, although they are not statistically significant, that the locus of motor output may vary with task and output demands.

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NOTE

1. Support for the idea that the latency differences obtained are indicative of something other than callosal transmission time comes from a comparison of latency differences of 11 Ss in this experiment with latency differences between ears of these Ss in a dichotic auditory experiment (Springer, 1971b). A positive, nonsignificant correlation was found ($r = +.32$). This very preliminary result is understandable if latency differences are related to uncertainty and processing strategies, which presumably would vary with the task.

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