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LATERAL ASYMMETRY: HARD OR SIMPLE-MINDED?

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Abstract—A letter or a three-dimensional shape was presented in the center of the visual field. Following the off-set of this stimulus either a comparison letter or a three-dimensional shape was flashed briefly in either the right or left visual field. The subject's task was to respond SAME, or DIFFERENT. The stimuli could be in the same plane, rotated in two dimensions (letters) or in three dimensions (three-dimensional shapes). The left visual field presentations (right hemisphere) of same-pair matches for letters only produced faster reaction times and fewer errors. In all other conditions reaction time measures showed no hemisphere effects. By contrast, error score data indicated that the left hemisphere was overwhelmingly more accurate.

INTRODUCTION

IN THE literature on hemispheric specialization, the verbal–non-verbal distinction has had theoretical pride of place, largely due to behavioral data on brain damaged patients. Aphasia almost never results from a right hemisphere lesion. However, the notion of brain cortex existing to subserve either language or pictorial representations has proved to be too simple and too specific a hypothesis [1]. As an example of the complexity of the issue take KIMURA's evidence that there is an aphasia related deficit in transitional fluency in sequential motor tasks performed by the contralateral hand for left hemisphere damaged patients, but not for right [2, 3]. The severity of this deficit in performance is correlated with the severity of the aphasia. She therefore suggests that transitional fluency and thus left hemisphere function is most characterized by processing *without* objects, i.e. internally programed action, this view borrowing from a theoretical formulation of LIEPMANN [4]. By contrast, according to this formulation, it is the right hemisphere which processes all *external* stimuli, determining their spatial relationships and performing operations on objects.

Further support for this sort of explanation comes from the work of GEVINS [5] who raises the issue that laterality differences in EEG spectra might disappear when appropriate controls are instituted. Thus, he discovered while monitoring EEG during verbal and non-verbal tasks, found in previous work to correlate with left or right hemisphere activation, that these differences disappeared when presentation rate, visual scanning, motor responses, and task difficulty were controlled. Gevin's current efforts are directed toward controlling out all such variables, leaving the cognitive dimension under scrutiny uncontaminated.

An equally fruitful approach might be to eliminate each artifact one by one, until it was determined which of them produced the laterality effect. This approach is taken in the current set of experiments which explore the issue of task difficulty. A series of four experiments carried out by SIMON *et al.* [6] provides a useful starting point. Letters and two dimensional geometric forms were presented to subjects. Letters were in either upright or rotated positions and subjects had to determine if the name was the same or different. Their hypothesis that rotated letter comparisons would elicit a right hemisphere advantage because of the "spatial" nature of the stimulus, was not upheld. No hemisphere effects were found. However, this result is inconclusive because subjects were required to name stimuli and the results derive from the additive effects of the verbal (naming) and spatial nature of the task.

Geometric form comparisons (no naming) produced the expected right hemisphere advantage. The authors conclude that although their results are suggestive they cannot resolve the issue raised by MOSKOVITCH [1] and others as to whether hemisphere effects are a result of stimulus properties or the kind of processing involved (motor or otherwise). As they note, "No study has shown opposite hemispheric asymmetries by varying stimulus characteristics within a fixed task".

The following experiment presents evidence using just such a task. We employed two kinds of visual stimuli: SHEPARD and METZLER's computer generated three-dimensional forms [7] and simple letter stimuli to investigate task difficulty—a control emphasized by Gevins which, if omitted, negates the interpretation of laterality effects. Shepard–Metzler figures in current parlance are perhaps the most "obviously" spatial sets of stimuli and hence would be expected to result in a right hemisphere advantage. COOPER and SHEPARD [8] have demonstrated that when these shapes are rotated in space, the time to task solution is a linear function of the actual time it would take to rotate these shapes *physically*. Mental rotation of external objects would, in Kimura's theory, be predictive of a right hemisphere superiority. Though opposite results have been observed [9].

Letter shapes have a verbal symbolic connotation. However, it has been demonstrated many times that simple matches to letters are most efficiently achieved by a "physical" match and not a verbal (name) match and thus favor right hemisphere processing [10, 11].

As a final control, we also used equal numbers of males and females and analyzed all results separately for sex. A large sex effect has been observed in reaction time and error scores on mental rotation problems [12]. Also, a number of studies on lateralization of function have revealed sex differences, most often with the findings that males show stronger laterality effects than females [13, 14].

In summary, this experiment investigates the impact of two variables: spatial analysis (rotation of form) and task difficulty (two dimensional familiar shapes vs three dimensional unfamiliar shapes) on stimulus presentations that are considered to favor right hemisphere processing. Mental rotations of objects in space should be, from Cooper and Shepard's results, the analogue of actual physical motion; and therefore the right hemisphere would, according to Kimura's theory, be superior to the left. If, however, mental rotation because of its time-locked nature is a sequential, analytic process, it could favor left hemisphere processing. Task difficulty ought, according to most hemisphere theories, to be independent of stimulus characteristics which favor one hemisphere or another. To test Gevins' assertion that task difficulty may be a major variable in producing hemisphere effects, other aspects of the experimental situation such as rate of presentation, motor response, scanning, etc., have been controlled.

METHODS

Subjects

The experiment was performed using right-handed volunteers as subjects: 20 males and 20 females. All subjects were Stanford students between 18 and 22 yr of age.

Apparatus

The study used an ICONIX three-field tachistoscope (unit 6137-3) and ICONIX electronic timing system, including preset controller (unit 6010), timebase and counter (unit 6255), logic cabinet (unit 6171) and lamp driver (unit 6192-3). The trials began with the illumination of the first field. The presentation card in the first chamber bore only a small dot in the center of the visual field (fixation point), and was left unchanged throughout the course of the experiment. The second field held the target stimulus (first of the stimulus pairs) and the third, the second stimulus. These stimuli were changed for each trial. The visual path distance was identical for each field.

Stimulus materials

The stimuli were of two types: letters and three-dimensional shapes. The letter stimuli were composed of $\frac{5}{8}$ in printed letters transferred from a letterpress sheet. The letters used were A, C, D, E, F, H, I, M, T, U, V, W, X and Y. The letters were placed at 3.5° to the left or right of fixation. They were then rotated clockwise in the plane of the card to a predetermined angle.

The letter stimuli were divided into three groups: letters with curves (C, D, U), letters with horizontal and vertical lines (E, F, H, I, T), and letters with slanted lines (A, M, V, W, X, Y). Target stimuli and second stimuli were then chosen from these groups. Members of the pair were chosen equally from the same group and from different groups. Thus some pairs were created in which the members, in their particular orientation, bore a strong resemblance to each other (e.g. V, upside-down A; E, sideways M; D, sideways U). However, the letter type was chosen so that no letter could be rotated in some way to look exactly like itself or another letter (e.g. M and upside-down W), and each subject was informed of this fact before the letter trials began. Both the "same" and "different" letter pairs were grouped by angular rotation, as follows: small rotation (60–120°), medium rotation (150–210°), and large rotation (240–300°).

The three-dimensional shape stimuli consisted of the series of 1½ in high computer-generated perspective line drawings used by SHEPARD and METZLER [7]. Each stimulus depicts a string of ten solid cubes, attached face-to-face to form a rigid structure, with exactly three right-angle elbows. Ten shapes were divided into two subsets. Each subset contained five distinct non-superimposable shapes, and each shape had a mirror-image shape in the other subset. By spatially rotating a shape in 20° increments, 18 different perspective positions (360°) were possible for each of the 10 shapes, corresponding to a full turn in either the plane of the presentation card, or in three-dimensional depth. Shapes were cut from a set of these drawings, and attached to presentation cards for use in the tachistoscope.

The Shepard–Metzler shape "same" pairs were grouped into three categories according to the angle of rotation. The categories were: small rotation (20°), medium rotation (40°), and large rotation (60 to 80°). The order of presentation of these pairs was determined at random. Approximately 75% of the "different" pairs were selected to be quite different from one another. For the remaining 25%, the mirror image was chosen as the second stimulus. In all cases, stimuli were chosen which displayed most of the shape in clear view.

All stimuli were matched in pairs (one target stimulus with one second stimulus); half the pairs were identical except in different rotations or perspective positions ("same"), and half were different ("different"). The order of presentation sequence for both types of stimuli was determined randomly. Each of the same-different categories contained 20 stimulus pairs, 10 to each visual field.

Procedure

Each subject was asked to look into the tachistoscope and center his/her attention on a fixation point. After a few seconds, the fixation point vanished, and the primary target appeared in the center of the visual field. Following target stimulus disappearance, the second stimulus appeared, on either the left or right side of the visual field. Half of the trials for each stimulus type were left visual field presentation and half were right visual field presentation, in a random sequence. The presentation time of the letter target stimulus was 1 sec following a 2.5 sec fixation period. After a ½ sec, the second stimulus appeared for between 50 and 70 msec.

Due to the complex nature of the three-dimensional shapes, subjects required longer presentation times for the target stimulus. The shape target stimuli were presented for 3 sec. A pause of ½ sec followed the disappearance of the target stimulus. The second stimuli were then presented for between 160 and 180 msec.

In all cases, several practice trials were run prior to the experiment to determine that the subject was indeed perceiving the second stimulus sufficiently well to make the determination of same or different. Subjects were asked to respond to stimuli by depressing one of two small buttons which were located at the midline of the subject's body. Responses were made using one finger of the right hand. Subjects' responses (same or different) and reaction times were recorded for each subject.

The test was conducted as follows: The subjects were asked to press one of two response buttons corresponding to their decision as to the similarity or difference between the target and second stimuli. The buttons stopped a timer, which had started concurrently with the appearance of the second stimulus. All subjects participated in all conditions of the experiment, making a total of 80 trials: 40 for the letter condition and 40 for the three-dimensional shapes. Following the trials, each subject was asked to recall any particular strategy or system used to make the same/different determinations for each type of stimulus.

Data analysis

Subject sex, stimulus presentation side (left visual field [LVF] or right visual field [RVF]), degree of angular rotation of the stimulus, and the type of stimulus pair ("same" or "different") were entered into two mixed ANOVA's, one using reaction time as the dependent variable and the other using errors on the task. In all cases of reaction time analysis, only "correct" responses were used. In error score analysis, the total number of errors made by the subject was used.

RESULTS

Letters

Same-pair judgments. An ANOVA for reaction time data to same judgments of letters shows a clear laterality effect with means for both males and females showing an advantage favoring the right hemisphere, $F\ (1,\ 38) = 17.36$, $P < 0.0001$. No other main effect or interaction reached significance.

The results for error scores to same pair judgments, showed that side of presentation (right hemisphere superior) was marginally significant, $F\ (1, 38) = 3.78$, $P < 0.06$. Also significant is the interaction between side of presentation and the degree of rotation of the stimuli, $F\ (2, 76) = 6.46$, $p < 0.003$.

The right hemisphere (LVF) was unaffected by rotation angle (errors ranged from 0.50 to 0.70), while the left hemisphere (RVF) was poorest with the small rotations (60–120°), and best with larger rotations (240–300°), errors ranging from 1.30 to 0.55.

Different-pair judgments. Reaction time data to different judgments were analyzed by an ANOVA. This analysis did not incorporate information on rotation angle, because the stimuli were of varying degrees of confusability and therefore could not be equated with one another. The results showed no significant effect for sex or side of presentation.

Error scores did, however, show an effect of hemispheres with a strong superiority for the left hemisphere (RVF), $F\ (1,\ 38) = 23.33$, $P < 0.0001$.

A significant sex effect was also found and is illustrated in Fig. 1, which shows large differences in errors between the visual fields for males in this task, and no differences for females.

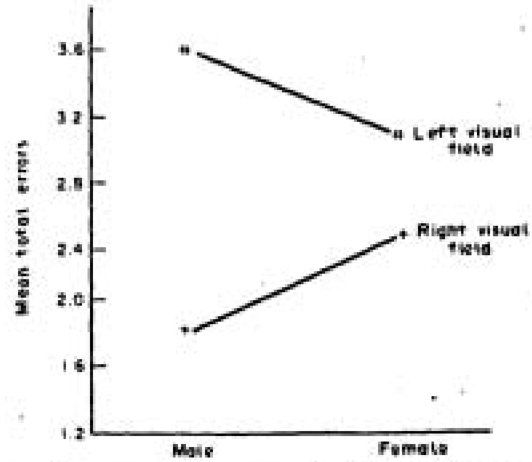

FIG. 1. Mean total errors for male and female subjects in making DIFFERENT judgments to letter stimuli.

It should be noted here that different pair judgments were marginally more difficult. Reaction time overall to same pairs was 1260 msec and to different pairs, 1280 msec. Same pair judgments produced a mean of 2.34 errors, whereas different pair judgments produced a mean error score of 2.70.

The right hemisphere was very efficient when responding to identical matches, but became inefficient as task difficulty increased. So far, only the left hemisphere was affected by the degree of rotation angle.

Three-dimensional shapes

Same-pair judgments. Reaction time to the three-dimensional shapes was unaffected by any of the variables under control. Quite a different picture emerges when error scores are analyzed. It is important to note that mean reaction time for both sexes combined were 2090 msec for the left visual field and 2150 msec for the right. When reaction time is so long, it ceases to be a truly valid indicator of central processing and error data are more reliable [15]. Side of presentation with the left hemisphere (RVF) superior was a highly significant effect, $F(1, 38) = 13.24$, $P < 0.001$, as was rotation angle, $F(2, 76) = 15.67$, $P < 0.0001$. These two factors interact to produce the effect illustrated in Fig. 2. Here the right hemisphere (LVF) is strongly affected by rotation, whereas the left hemisphere (RVF) is not, $F(2, 76) = 9.70$, $P < 0.0001$.

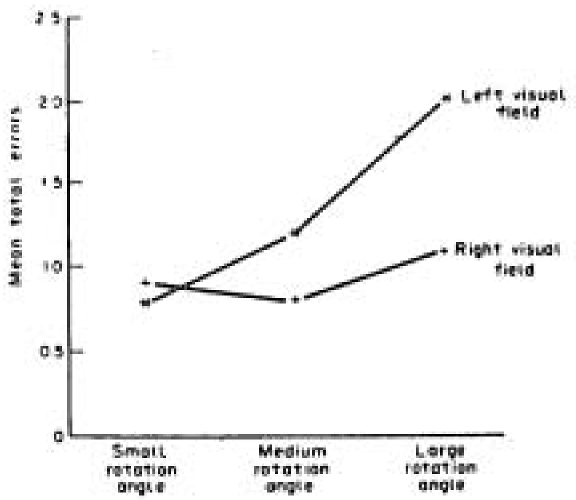

FIG. 2. Mean total-errors for all subjects in judging SAME-PAIR matches to three-dimensional shapes presented at small (20°), medium (40°), and large (60–80°) angles of rotation.

Different-pair judgments. As in the letter condition, degree of rotation was not incorporated as a separate variable in analyses, due to the impossibility of controlling for levels of difficulty. There were no significant effects for sex or hemisphere in reaction time.

Error scores, however, produced a highly significant difference favoring the left hemisphere, $F(1, 38) = 68.60$, $P < 0.0001$. The mean error score for the left hemisphere (RVF) was 3.4, and for the right (LVF) 6.1. Once again, error data are more revealing than data from reaction time scores. No sex effects were significant in this task.

Letters and three-dimensional shapes compared

Same-pair judgments. As would be expected, reaction time to letters was significantly faster than to shapes. $F(1, 38) = 50.55$, $P < 0.0001$. Also, the right hemisphere is faster when the data from both tasks are combined, $F(1, 38) = 5.48$, $P < 0.025$.

The degree of these differences is represented in the bar graph, Fig. 3. The analysis for error score data showed that more errors occurred in the three-dimensional shape condition, $F(1, 38) = 13.92$, $P < 0.001$, as might be expected. A significant interaction between type and side, $F(1, 38) = 23.74$, $P < 0.0001$, is illustrated in Fig. 4.

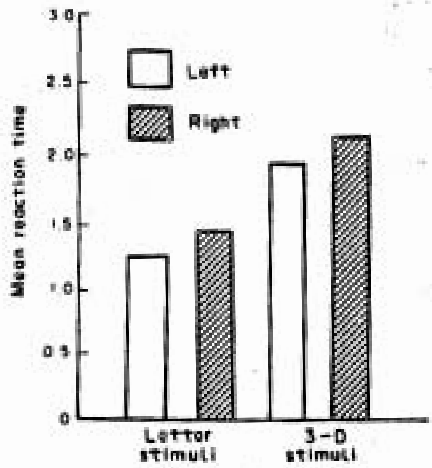

FIG. 3. Mean reaction time for all subjects collapsed across all conditions for letters and three-dimensional shapes presented to the right or left visual field.

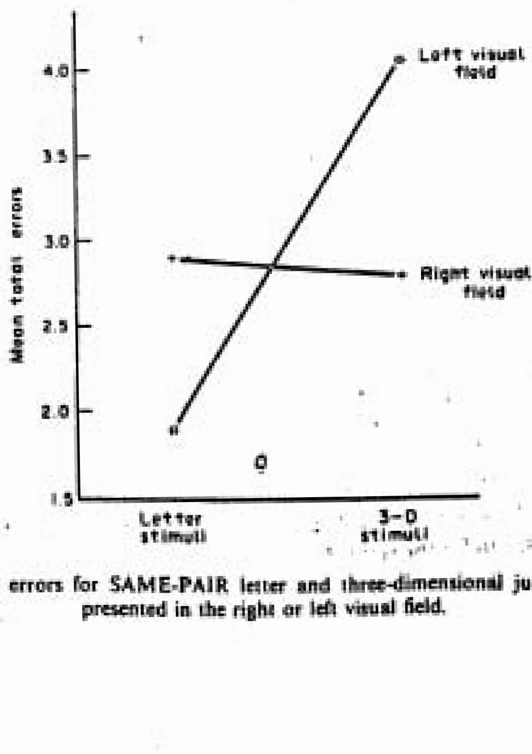

FIG. 4. Mean total errors for SAME-PAIR letter and three-dimensional judgments to stimuli presented in the right or left visual field.

The left hemisphere (RVF) appears to process both letters and shapes equally well. Only the right hemisphere (LVF) is affected by task type, or perhaps more accurately in this case, task difficulty.

Different-pair judgments. The different-pair judgments produced similar results: in the reaction time data the only effect to reach significance was the type of stimulus. Letter tasks were carried out faster than three-dimensional tasks. No other effect, hemisphere, sex, or the interactions between these variables reached significance.

The error data, however, confirm the findings above. Type of stimuli is significant, $F(1, 38) = 47.62$, $P < 0.0001$, with letters perceived more accurately. Side of presentation is significant, with the left hemisphere (RVF) more accurate, $F(1, 38) = 76.35$, $P < 0.0001$.

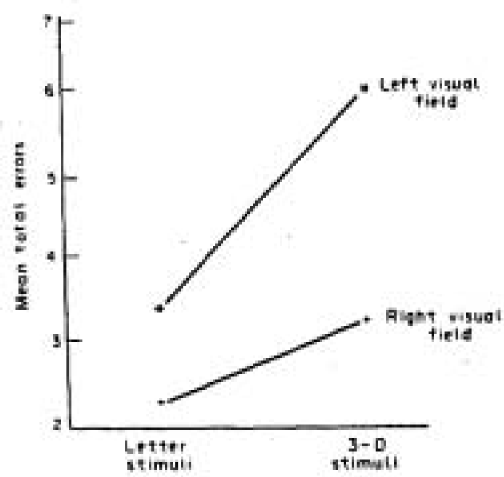

FIG. 5. Mean total errors for DIFFERENT-PAIR letter and three-dimensional judgments to stimuli presented in the right or left visual field.

The two-way interaction Type × Side, $F(1, 38) = 18.25$, $P < 0.0001$, is shown in Fig. 5. In contrast to the same-pair judgments, the different-pair judgments are far more accurate when stimuli are presented to the left hemisphere in both letter and shape conditions. The right hemisphere is particularly inaccurate when comparing three-dimensional shapes that are different in form.

DISCUSSION

As set out in the Introduction, these experiments were designed using stimuli that were believed to favor right hemisphere processing. In only three comparisons was this assumption borne out. First, the responses were faster overall to stimuli in the left visual field, but only when all stimulus conditions were combined. In individual comparisons the only difference favoring the right hemisphere was in speed of response to same-letter pairs. This finding was further substantiated in the analysis of error scores—showing the right hemisphere superior. These results confirm the well documented physical shape match superiority for the right hemisphere reported by several investigators [10, 11].

However, in all other analyses of reaction time, no hemisphere effect emerged, and when considering error data, with the exception mentioned above, the left hemisphere was overwhelmingly more accurate.

Influence of task difficulty

These results suggest that any manipulation that makes a simple target match more difficult, such as rotation or use of complex or contrasting comparison stimuli, will produce responses that reflect a different mode of processing favoring the left hemisphere. Subject reports indeed confirm this. All subjects (males and females) said that verbalization of the letter forms became necessary only when there were different-pair comparisons, and more especially when rotation produced confusion and made the judgment more difficult. Similarly, when asked to report on strategies adopted during the three-dimensional shape presentation, subjects frequently reported isolating features of the target and mentally relating them to the comparison stimulus. Features cited were the number of arms bending from a central axis, number of blocks on the end arms, the direction of the arms, etc. Despite the fact that Shepard shapes are considered to require spatial visualization, as far as we could tell, image comparisons required verbal or some symbolic form of sequential analysis.

Though the right hemisphere processed items faster, it was generally imprecise in most conditions. This dichotomy between speed and accuracy, showing the left hemisphere primed for accuracy, the right primed for speed, is an interesting effect, and may help to explain the dissociation between RT and error data which has been shown to occur after approximately 2000 msec. A formal mathematical model of the speed–accuracy trade off has been presented by WICKELGREN and his colleagues [16]. REED [15] initially described this function as a negatively accelerating curve, which assymptotes at about 2 sec in situations where items in memory must be held and matched or primed by stimulus presentation. After this period, the relationship between speed and accuracy breaks down.

Angle of rotation

The results from the analysis of rotation angle are more complex. In the same letter pair judgments, the right hemisphere appeared unaffected by angle of rotation—whereas the left hemisphere was strongly affected. This finding is somewhat problematic with respect to the degrees of rotation angle involved in this task. Items were rotated from 60 to 300° in a clockwise direction. In theory, there should be no difference between the two angles of 60 and 300° as they represent an identical deviation from zero. The only difference between them is that items rotated at 60° would be oriented leftwards and those at 300° oriented rightwards. It is important to note, however, that the rotation effect was extremely weak and that there was no main effect for angle of rotation in reaction time data or in error scores when field differences were collapsed. This does not alter the fact that same-letter pairs presented to the right hemisphere are processed faster and more accurately. REED [15] reports that in rapid visual matches accuracy has a linear relationship to time of response.

These results contrast dramatically with the effect of rotation angle in the three-dimensional task which appeared in the accuracy data. Here the main effect of rotation angle was highly significant, as was the field × rotation interaction. Paradoxically, although the subject reports confirmed a large number of symbolic sequential processing strategies, these strategies, rather than slowing down processing efficiency, actually improved it. On the other hand, the right hemisphere, without access to these strategies produced more and more inaccurate responses as the rotation angle deviated from zero (see Fig. 2). These findings have implications for research on spatial visualization in general. The assumption that these tasks are best performed by the right hemisphere, appears to hold only when stimuli are two-dimensional and judgments are relatively easy. In complex three-dimensional spatial visualization such as the Shepard task, not only is the left hemisphere more accurate and

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equally as fast as the right, but the right hemisphere becomes increasingly inefficient as the task gets more and more difficult. These findings support the results showing left hemisphere EEG activation in a "spatial" task reported by ORNSTEIN and his group [9].

What are the implications then for the issues raised in the introduction to these experiments? It seems clear that the continuum of task difficulty, easy–hard, is a critical factor in producing hemisphere laterality effects. The more difficult the task, the less automatic or parallel processing is possible, and the more sequential and/or verbal strategies become involved. This conclusion is similar to that of DERENZI's in his summary of research on spatial tasks [17].

Transitional fluency and the perception of objects

The data indicate that if transitional fluency, a left hemisphere function [2, 3], plays a role it must do so at the initial target presentation stage (S1) and would be involved in the rapidity with which features of a complex form are scanned, ordered, and represented in short-term memory. This must be so because the response times produced from the onset of S2 (the comparison stimulus) are *identical* for presentations in the right or left visual field. Further, the consistently high accuracy of left hemisphere performance showing no decline in proficiency as rotation angle increases, nor any difference between the simple letter or complex three-dimensional tasks (see Figs 4 and 5), confirms the view that the representation in the left hemisphere is considerably richer, while that in the right is impoverished.

The view held by KIMURA [3] that the left hemisphere deals with execution of internally controlled acts could be confirmed by these data. A serial search process *is* an internally controlled strategy. The fact that this left hemisphere strategy is more effective in dealing with an analysis of objects in the world, however, runs counter to Kimura's other proposal that this is the province of the right hemisphere. It appears that no such dichotomy as Liepmann's original formulation can be applied when problem solving strategies are involved. Subjects will use whatever and as many strategies as they find efficacious.

These findings, coupled with the subjective reports on strategy pose some difficulty for untangling a verbal–visual dichotomy as compared to a serial–parallel dichotomy. As MOSCOVITCH [1] points out, the right hemisphere might also operate in serial mode if a series of successive eye movements were required. Indeed, the linear relation of errors to rotation angle for LVF presentations in the three-dimensional tasks suggests just such a strategy—that the right hemisphere is carrying out a series of "looks" on a fading icon (S2) and that this becomes more inaccurate as the task increases in complexity. The question remains, however, if verbalization of any kind were made impossible, would right hemisphere processing be more efficient in complex judgments of spatial form?

Sex differences

One sex difference emerged in these data and that occurred in responses to different letter pairs. Males showed a large hemisphere effect with the left hemisphere noticeably more accurate than the right. This finding could indicate that the males used more verbal strategies in this case than females which seems unlikely due to the consistent reports of females' reliance on verbal modes of thought [18], or it could indicate, as MCGLONE [13] has suggested, that females have a greater representation of verbal skills in the right hemisphere. As no other sex variation is significant, there is little support for any general theory of sex differences in hemispheric functions, other than to state that simple naming skills could be more bilaterally represented in females, whereas complex symbolic analytic processing appears unique to the left hemisphere in both sexes. It is important to note, also, that no sex differences were found in reaction time or error scores to the rotated three-dimensional shapes, nor have we noted any sex differences in other three-dimensional visualization tasks in the Stanford population.

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Résumé

Une lettre ou une forme tridimensionnelle sont présentées dans le centre du champ visuel. Après l'extinction de ce stimulus, soit une lettre, soit une forme tridimensionnelle est projetée pendant un temps très bref dans la partie droite ou gauche du champ. La tâche des sujets est de répondre si la lettre ou la forme projettée brièvement est semblable ou différente de celle qui avait été montrée au centre du champ. Les stimuli à comparer entre eux peuvent être soit dans le même plan, soit tournés l'un par rapport à l'autre en deux dimensions (lettres) ou en trois dimensions (formes). Les présentations dans le champ visuel gauche (à l'hémisphère droit) de stimuli identiques à ceux qui avaient été préalablement présentés (mais seulement lorsqu'il s'agissait de lettres) ont donné lieu à des réponses à temps de réaction plus court et avec moins d'erreurs. Dans toutes les autres conditions, les mesures de temps de réaction n'ont pas montré d'effet de l'hémisphère. Par contre, la mesure du nombre d'erreurs a montré que l'hémisphère gauche était de loin le plus précis.