HEMISPHERIC ASYMMETRY IN PROCESSING VISUAL STIMULUS ORIENTATION

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ABSTRACT

This study investigated the possibility of differential processing by the two cerebral hemispheres in recognizing the second of two successively presented digits. The second digit was either normally oriented or else it had been rotated 180° around one of three different axes of visual space. A same-different reaction times task was used with three factorially combined within-subjects variables: Stimulus Position (Left, Right Visual Field) x Orientation (Normal, Rotated) x Hand (Left, Right), and one between-subjects variable: Axis of Rotation (X, Y, Z). An interaction was obtained between Stimulus Position and Orientation; normal and rotated forms were processed equally well when presented in the left visual field, whereas in the right visual field there was a significant difference in favour of the normally oriented forms. The results indicate that the left and right cerebral hemispheres may differ in how they process spatially transformed shapes.

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INTRODUCTION

The lateral mirror-image transformation seems to be unusual compared to other orientational changes of a visual stimulus. A number of studies with animals (rat, cat, monkey, goldfish, octopus, pigeon) have shown that more errors of discrimination occur between lateral mirror-image stimulus pairs than upside-down mirror-image pairs (Corballis & Beale, 1970; Over & Over, 1967). Interocular transfer studies by Mello (1965, 1966) with pigeons, and by Noble (1968) with monkeys have indicated that the lateral mirror-image transformation is special: negative interocular transfer was found, whereas positive interocular transfer occurred for upside-down mirror-image pairs, and for geometrically dissimilar forms. Humans show more errors and longer reaction times for lateral than for upside-down mirror-image discriminations (Over & Over, 1967; Sekuler & Houlihan, 1968). It is common for young children to laterally reverse letters and numbers in learning to read and write, although other orientational reversals are rarely made (Frith, 1970). The continued manifestation of these reversals is the primary symptom of dyslexia, which occurs in about one out of every forty children (Ginsburg & Hartwick, 1971).

There have been four basic theories proposed to account for performance difficulties observed with lateral mirror-image discriminations, including dyslexia. One is based on animal research and posits a neurological origin: the corpus callosum, in combination with the structural bilateral symmetry of the cerebral hemispheres, may mediate lateral reversals. This could occur either perceptually or mnemonically (see Corballis and Beale, 1970; Mello, 1966; Noble, 1968). Another explanation is that the basis for lateral mirror-image confusion is behavioural. This argument counters the previous one, suggesting that peculiarities of the testing situation can explain the mirror-image difficulties (Beale and Corballis, 1968; Hamilton, Tieman and Winter, 1973). A third explanation, directed at dyslexics' difficulties is that "mixed laterality" is at fault. The idea here is that the right hemisphere has lateral mirror-image engrams with respect to the left and confusions between veridical and mirror-image forms occur if one hemisphere is not functionally dominant over the other for linguistic processing (Orton, in Ingram, 1969). A fourth explanation is that there is a special mechanism for orientation which malfunctions to cause improper coding of orientation (Kolers, 1972). None of these explanations, however, is entirely consistent with the evidence. The following discussion will attempt to concentrate on their relative explanatory powers.

Lateral mirror-image stimulus pairs give anomalous results in the interocular transfer task. This task involves monocular viewing, with direct visual projections from each eye either surgically or naturally lateralized to one cerebral hemisphere. In the case of the pigeon, each eye projects solely to the contralateral hemisphere naturally; however, in mammals the fibers at the optic chiasm must be sectioned in order to lateralize input to one hemisphere (in this case, the one ipsilateral to the eye). In the training period, an animal is rewarded for the choice of one of two shapes until his performance reaches a predetermined criterion. In the test phase that follows, the previously occluded eye is used and the eye previously used in training is now occluded. The stimuli are unchanged, and the task for the animal is to perform the discrimination for which he had previously been trained. Trials are either nonrewarded, or both shapes yield reward. Positive interocular transfer is evident when the animal responds more often to the shape which was rewarded during training, while negative transfer occurs if the animal shows a preference for the previously unrewarded shape.

Normally, positive interocular transfer is anticipated in this task. This is found when the visual stimuli are upside-down mirror-image pairs or geometrically dissimilar visual forms (Mello, 1966; Noble, 1968). Negative interocular transfer is obtained with pigeons, goldfish, and monkeys when lateral mirror-image pairs of visual stimuli are used (Mello, 1966; Campbell, 1971; Noble, 1968). The latter is not a uniform finding, however, in that not all of the lateral mirror-image pairs yielded negative transfer in Mello's study (1966), and the preference for the negative shape was only evident after the first several trials in the monkey (Noble, 1968). Furthermore, Hamilton, Tieman & Brody (1973) used a matching to sample variation of the interocular transfer test and found positive transfer for upside-down mirror-image pairs, but chance-level responding for the lateral mirror-image pairs.

Mello suggested that if there were a one-to-one spatial mapping visually for the two hemispheres, then this reversal could be easily explained as an artifact of interhemispheric transfer. Because the two cerebral hemispheres are lateral mirror-images with respect to each other, one-to-one spatial mapping would result in a reflection about the midline between them (see Figure 1). Noble applied the same explanation to mammals; he further suggested that direct optic information normally overrides the indirect (callosally transmitted) information, so that normally veridical information is perceived, with the callosal information being perhaps accessible. Noble suggested that this dual input would sometimes be in conflict, causing lateral mirror-image difficulties in perception.

Corballis & Beale (1970) have suggested that if interhemispheric reversal does occur, then it is likely to be at a later temporal stage than Noble theorized. They suggest that mirror-reversed memory engrams are shared interhemispherically at some point after the actual perceptual

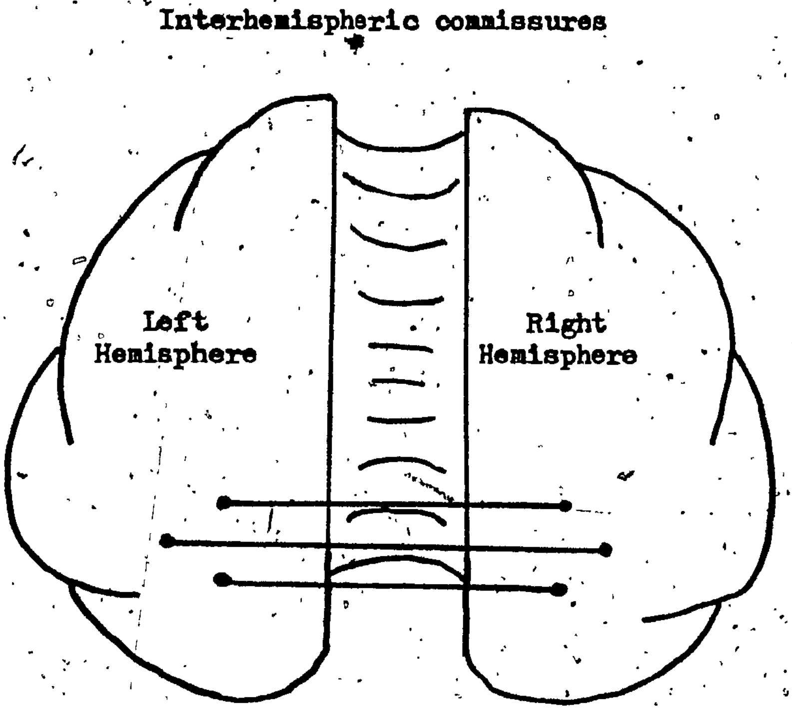

FIGURE 1: Point-to-point spatial mapping between the two cerebral hemispheres.

exchange, which would be veridical. They pointed out that this interpretation is compatible with the callosal reversal studies of Mello and Noble. They gather further support from Over and Over (1967), who found that children had much greater difficulty in a recognition task than a detection task with lateral mirror-image stimuli.

The interhemispheric commissures are suspect as the mediator of these reversals because they appear to be the primary transmitters of information of one hemisphere for another. When they are sectioned, interocular transfer generally does not occur (Myers, 1961; Noble, 1968; Sperry, 1961). When the optic chiasm is intact and the corpus callosum is severed, transfer is positive. In this case, input is not lateralized to one or the other hemisphere. The only situation in which interocular negative transfer is found occurs when lateral mirror-image visual stimuli are used, and interhemispheric transfer of information is required during testing.

There are other findings which imply interhemispheric transmission of mirror-image equivalence. Unoperated pigeons were trained to peck at an oblique line stimulus, and a generalization gradient was obtained as the line was rotated through 90°. The result was a bimodal gradient, with one peak at the original stimulus and another at its mirror-image. However, birds with sectioned interhemispheric commissures gave unimodal gradients, with the peak at the original stimulus orientation (Beale, Williams, Webster & Corballis, 1972).

One interpretation of these findings was suggested originally by Beale and Corballis (1968), who argued for what they call a "beak shift" notion. They found that pigeons tested for interocular transfer tended to favour one side of the key over the other, and that the side favoured was usually that of the seeing eye. In this case, the bird was pecking a different side of the key for each eye. Beale & Corballis (1968) concluded that the extent to which pigeons lateralized their pecking determined the extent of interocular mirror-image reversal. They further suggested that a pigeon was only attending to one side of each stimulus; this means that each stimulus line would occupy only an upper or a lower quadrant of the circle in which it was drawn. When the opposite (untrained) eye was used, attention was switched to the opposite side of the stimuli, and the stimulus which had previously occupied the upper quadrant was now seen in the lower one, vice-versa for the other stimulus. Thus, if a bird was pecking on the basis of quadrant, or the side of a visual stimulus, he would reverse his preference in the transfer test.

These notions have received some recent support. Lehman and Spencer (1973) found that monkeys were fixating rigidly on the center of the patterns, so that when their optic chiasm was sectioned they only saw (or attended to), one half of each stimulus. The side attended would be opposite for each visual half-field. These researchers trained monkeys with sectioned optic chiasma to discriminate monocularly between a diamond and a square pattern. In the test phase, one of the shapes had a right-sided resemblance to the previously rewarded square, and a left-sided resemblance to the diamond (termed "right polarity"). The other shape had a left-sided resemblance to the square and a right-sided resemblance to the diamond ("left polarity"). The pair looked something like this:  . Animals tested with the right eye preferred right-polarity shapes. The authors concluded that the optic-chiasm-sectioned animals had a tendency to pay greater attention to the opposite side of each shape with each eye, and that this tendency can explain interocular reversals with lateral mirror image forms.

Hamilton, Tieman & Winter (1973) trained animals to discriminate between stimuli:  vs.  and  vs.  , each pair being the same on the right half and different on the left. When the subjects viewed stimuli with the left eye, the task was very difficult (a mean of 2,394 trials to criterion), but the task was easy with the right eye (a mean of 71 trials to criterion). These relations were reversed when the stimuli were rotated through 180° ( vs.  and  vs. ). The investigators suggest that, again, the animals were only attending to cues on one side of each stimulus.

All in all, the behavioural explanations seem to give a more plausible account of the happenings in the interocular transfer testing than the callosal reversal theories.

The third and fourth explanations suggested earlier were proposed specifically to account for dyslexia. Several investigators have found a high incidence of left-handedness, inconsistent lateral preferences and ambidextrality in their samples of dyslexics as contrasted with normal populations (Ingram, 1969; Zangwill, 1962). In most right-handers the control of speech production is lateralized to the left hemisphere; however, the proportion for this left-hemisphere dominance for speech is considerably smaller in non-right-handers (Branch, Milner and Rasmussen, 1964). In the 1930's Orton (cited in Ingram, 1969) suggested that there is no strong or consistent lateralization of control for linguistic processing in dyslexics, and that the right hemisphere has memory traces which are lateral mirror-images with respect to the left. Mirror-image confusions could be made because of the conflicting hemispheric information.

Other theories have proposed an orientational processing mechanism which could malfunction to cause spurious reversals or misperceived orientations (Kolers, 1972). None of these, however, are stated in precise terms, either anatomically or in terms of their specific behavioural implications.

All told, none of the explanations is entirely convincing. The evidence does suggest, however, that the lateral mirror-image is a special case among stimuli, and any information gained as to how it is processed could have implications for dyslexia.

Research with humans who have had their corpus callosum severed (the so-called "split-brain" patients), and other clinical studies of patients with unilateral cerebral damage, have indicated that the two cerebral hemispheres are differentially specialized (Gazzaniga, 1970; Milner, 1969). The separate functioning of the two hemispheres in these patients can be studied with divided visual fields. More recently, experimental studies have been carried out using divided visual fields and normal subjects, with reaction time measures. The clinical and experimental data from normal and split-brain subjects have generally produced consistent findings. With unilateral presentations of pictures, random patterns, words, and letter stimuli, verbal stimuli are processed more quickly when presented to the right visual field while nonverbal stimuli are, in general, processed faster when projected to the left visual field (Gazzaniga, 1970; Geffen, Bradshaw & Nettleton, 1972; Rizzolatti, Umilta, & Berlucchi, 1971).

In normal subjects one cannot necessarily assume that the hemisphere to which the stimulus is projected is that which actually processes the decision. The longer reaction times for different types of stimuli in the separate visual fields could reflect the extra time taken for the stimulus to cross via the callosum in order to be processed by the hemisphere specialized for the task, or it could simply reflect relative temporal efficiencies of the hemispheres.

Several investigators have used a reaction time technique in which a subject must decide whether two letters have the same name or not (e.g., Posner & Taylor, 1969). When the two letters do have the same name, they may be the same in name only (e.g., A a), or they may be physically identical (e.g., A A). Recently, Cohen (1972) and Geffen, Bradshaw & Nettleton (1972) have found that subjects are faster in making a name identity match with stimuli shown in the right visual field, and that the physical identity match is made faster with stimulus presentations in the left visual field. These results suggest that the hemispheres are specialized not merely for certain types of stimuli (e.g., linguistic versus non-linguistic), but for the type of processing that is demanded: in this case, whether two stimuli can be processed as two visual forms, or must be processed as names.

It may be that one hemisphere is relatively more efficient in processing familiar symbols that have been spatially transformed than the other. This possibility is suggested by a recent study by Taylor (1972a), in which subjects were required to decide whether a string of words described the same number as a pair of digits. The words were stored in memory, while the digits were presented for comparison with these. The digits could be either normally oriented or rotated in any one of the three spatial dimensions (X, Y, or Z axes of rotation in a gravitational-relative Cartesian coordinate system). The reaction times were found to be consistently faster when the rotated digits were presented in the left visual field, but the normally oriented digits yielded faster reaction times in the right visual field. The left hemisphere may therefore be showing greater efficiency for the digits in their familiar orientation, while the right was relatively more efficient when the shape was in a less familiar orientation. In a similar vein, Braine (1972) found that when the distinguishing cue of her rotated geometric figures was on the left side, the reaction times for recognition were faster than when they were on the right.

The purpose of the present study was to investigate the possibility that there may be laterality effects in the recognition of spatially transformed figures. The study of Taylor (1972) had some suggestion that this is a possibility. Furthermore, laterality research in general and the studies of Geffen et al. (1972) and Cohen (1972) in particular suggest the possibility that each hemisphere processes visual stimuli in different ways.

Two variables were used which might possibly show laterality effects. One of these was stimulus position, with right and left visual fields as the two possibilities. Each visual field projects only to the contralateral cerebral hemisphere, so that this is a source of anatomical lateralization. Hand used for responding was also a variable. Control and coordination of each hand is primarily a function of the contralateral cerebral hemisphere (Gazzaniga, 1970; Sperry, 1964). Thus, any systematic relationships between visual field and hand could imply an underlying relationship involving different hemispheric functioning. However, the lateralization of hand control is not complete, so that the hemisphere ipsilateral to the hand may direct the hand's response (Gazzaniga and Sperry, 1967). A third variable was orientation, with two levels: normal orientation and a rotated orientation. The normal orientation served as a baseline for comparison with the rotated form in each visual field and with each hand. These three variables were all factorially combined within-subjects variables. The fourth variable, a between-subjects measure, was axis of rotation used for the rotated stimulus. Three different axes were used, yielding three different mirror-image stimuli, the lateral mirror-image transformation being of greatest interest because of the literature which indicates greater difficulty and confusability with this than with upside-down mirror-image stimuli.

METHOD

Subjects

Subjects were right-handed adults with ages ranging from 16 to 30 years. All were students at Memorial University at either the graduate or the undergraduate level. Handedness was determined by subjects' verbal report.

A total of 72 subjects was used for the series of experiments. Twenty-four were used for each of Experiments I, II and III. The subjects who served in Experiment III also served in Experiment IV. Half of the subjects were male and half were female in each experiment.

Stimuli

The stimuli were digits which were presented on a cathode ray tube (CRT), which was of dimensions 18 x 26 cm. The digits used were: 1, 2, 3, 4, 5 and 7. Each subtended a horizontal visual angle of 18', and a vertical angle of 30', ± 10' as subject moves his head. Presentations and timing of events within a session were controlled by a Hewlett-Packard 2114A computer. This system is described more completely by Taylor (1972b). Three displays were used. The stimuli of the three displays all subtended the visual angle vertically of that of a single digit: 30'. The stimuli of the first display subtended a horizontal visual angle of 38', ± 21'; for the second display it was 18' ± 10', and for the third it was 1°21', ± 45'.

Procedure

All subjects were first given uniform written instructions as to the events within a session (see Appendix A).

Each trial consisted of three sequential visual displays on the CRT. The first display consisted of two adjacent digits at the centre of the CRT screen. One of these (always situated left with respect to the other) was a reference digit, and the other was a target digit. These two stimuli stayed on the screen for a period (defined later) called the Standard Interval (SI). At the end of the first SI, the target digit disappeared, leaving only the reference digit in the centre of the screen; the duration of this display was also equal to SI. The third display was presented at the end of the second SI; this consisted of the reference digit and a test digit. The task of the subject was to determine whether or not the target and test digits were the same number, requiring a "yes" or "no" answer. The time limit for a response was also SI. If the subject did not respond within this interval, or if he answered incorrectly, a large "X" appeared in the centre of the screen and the trial was terminated. The reaction times of these error trials were not recorded. If the subject responded correctly within SI, his reaction time was printed in the lower left hand corner of the CRT and the trial was terminated. This reaction time defines the response interval (RI).

The sequence of events would be something like the following: "45"...."4"...."47" (requiring a "no" response) or "37"...."3"...."37" (requiring a "yes" response). See Figure 2.

The test digit appeared for 50% of the trials to the left of the <u>reference</u> digit and 50% of trials to the right of the reference digit, these positions being randomly distributed. 50% of trials were allotted to "yes" and 50% to "no", also randomly assigned throughout a session.

Subjects indicated their answer by pressing one of two response buttons. These two buttons were 2 cm. apart, and the leftmost one always signalled the "no" response and the rightmost one always signalled the "yes". Using the right hand, the middle finger controlled the "yes" button and the index finger controlled the "no" button. With the left hand these relations were reversed, with the index finger controlling the "no" button and the middle finger controlling "yes".

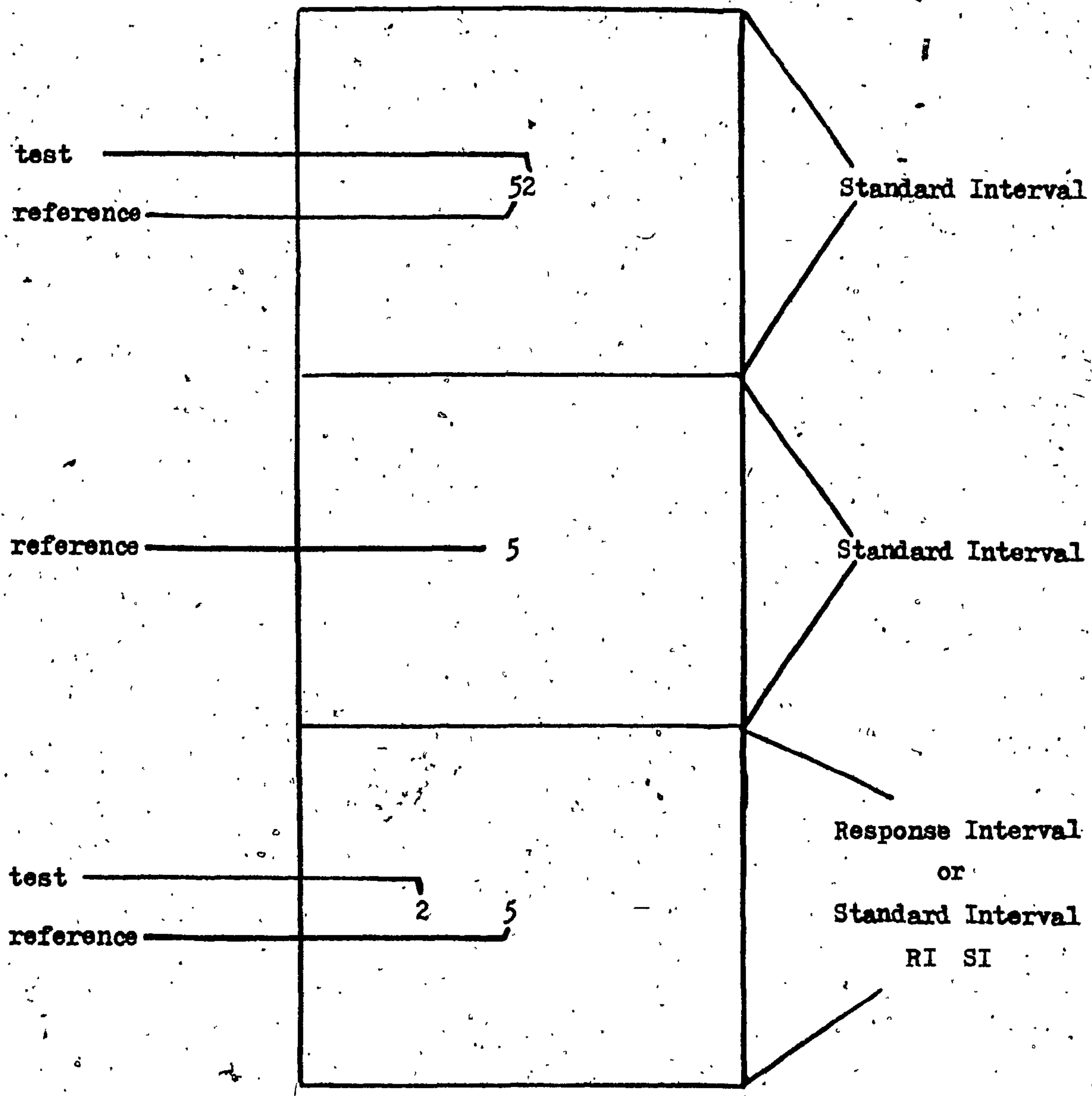

FIGURE 2: Three visual displays of a typical trial

The first two digits, the reference and the target digits, were randomly chosen from the pool of the six stimulus digits, with the constraint that these could not be the same as either the reference or the target digit. They were randomly selected from the remaining four possibilities. In the case of a "no" trial the test digit could not be the same as either the reference or the target digit and was randomly selected from the remaining four digits.

Temporal Scaling

Boredom and unnecessary double-checking produce excessively long reaction times. The subject also fails to attend on occasional trials. These behaviours constitute sources of inhomogeneity which are common in reaction time tasks. One technique to avoid this inhomogeneity is to throw out trials which exceed an arbitrary statistical criterion of being too long. But that procedure does not attack the source of the inhomogeneity because it fails to inform the subject that taking too long constitutes an error. Similarly, any arbitrary statistical criterion is fallible in rough proportion to how thoroughly a subject's performance is laced with these inhomogeneities, which have not been estimated directly.

The procedure used in this experiment was to establish a time limit for responding and adjust exposure durations of the stimulus arrays on each trial, for each subject, at a value near the upper end of his cumulative reaction time distribution. In this way, the time scale of a trial and permissable reaction times were lowered progressively throughout a session as the risks of boredom and inattention increased (Taylor, 1972).

The subject initiated each trial by pressing both response buttons, thus insuring that the intertrial interval met his changing criterion of readiness throughout a session. If the subject did not start another trial immediately, a ready signal was presented during the intertrial interval. This signal was a flashing line with an on/off cycle of 75 msec. It appeared in the lower left hand corner of the CRT.

The SI began at 1500 msec. for the first trial; for subsequent trials it was the lesser of 1500 msec. or the cumulative mean of the subjects' reaction time plus three standard deviations. The three visual displays for trial n+1 were each exposed for SI_n. The time limit for responding during the test interval of trial n+1 was also SI. The SI was recalculated on each trial by the computer.

Two minima had to be satisfied before the completion of each session. One of these minima was that the session was of duration at least 20 minutes, and the other that at least 250 trials had been completed. When both of these minima were satisfied, then no further stimuli or ready signals were generated by the computer and the screen was blank. Subjects had been given prior instruction that the sessions would be complete at this point.

Reaction times of correct trials were recorded as the dependent variable.

Experiments I, II and III

For each of these three experiments the test digit was normally oriented for 50% of trials and for the remaining trials it was rotated 180° about a specific geometric axis for each of the experiments (see Figure 3). These rotations are described more completely by Taylor (1972a).

In Experiment I, Y was the axis of rotation, yielding the Y transformation.

In Experiment II, X was the axis of rotation, giving the X transformation.

In Experiment III, Z was the axis of rotation, giving the Z transformation.

Each subject performed two sessions, one with the right and one with the left hand. This variable was counterbalanced in order of first session: half of the subjects did the first session with the left hand and half did the first session with the right hand.

Each experiment thus had three within-subject factorially combined variables: Stimulus Position (Right, Left Visual Field), Orientation (Normal, Rotated), and Hand (Right, Left).

In the combined analysis for Experiments I, II, and III, there was also a between-subjects variable: Axis of Rotation (X,Y,Z).

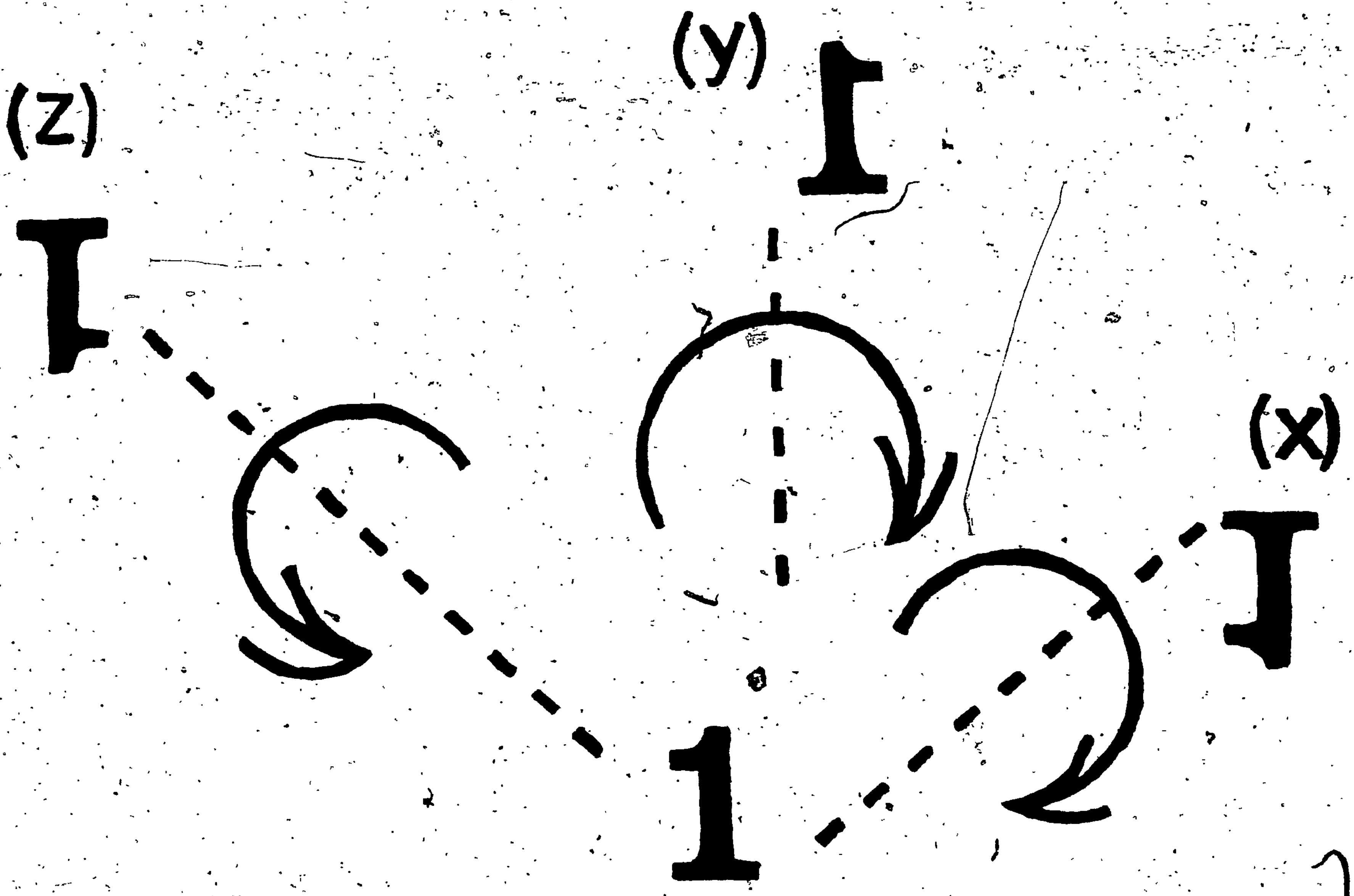

FIGURE 3: The digit "1" as it appears normally and after 180° rotations around its X, Y and Z axes (Taylor, 1972a, p. 396).

Experiment IV

There was one session only for Experiment IV, using the right hand. Subjects who had performed Experiment III served as the subjects also for Experiment IV. They did three experimental sessions in all, Experiment IV being always the third session. One-third of the test digits were from each of the Y, X and Z transformations, randomly distributed throughout the session.

In the analysis of variance for Experiment IV there were only two variables. These were Stimulus Position (Right, Left Visual Field) and Orientation (X,Y,Z). These were factorially combined within-subjects variables.

RESULTS

A four-way analysis of variance was run for the Experiments I, II, and III combined, using Balanova 5 (see Table 1). The only effects significant beyond the .01 level were the main effect of orientation, and the interaction of Orientation x Stimulus Position, F(1,69= 19.05, $p<.001$. The means for this interaction are shown in Table 2.

A multiple comparisons test (Hays, 1963) with alpha set at .01 and using the means for the Position x Orientation interaction, revealed that the cell means must differ by at least 35.8 msec. in order to have reliably contributed to this interaction. The difference between reaction times for normal and rotated stimuli was 38 msec. in the right visual field, and only 4 msec. in the left visual field. Thus, the finding was a simple main difference between reaction times when digits were normal or spatially transformed in the right visual field.

The means in Tables 2 and 3 have been averaged over the variable "Hand". This variable was not significant in main effect, nor in interaction with any of the other variables in the combined or the separate analyses which were performed on these experiments. The mean reaction times for individual subjects are shown in Appendix B. Appendix C shows analyses of variance for the experiments separately.

Table 1

Summary table of analysis of variance combining Experiments I, II and III.

Source	Denominator	Degrees of Freedom Num	Den	Mean Square	F Ratio
Within Subjects					
Stimulus Position (A)	AxS	1	69	453	0.138
Orientation (B)	BxS	1	69	64830	23.76**
Hand (C)	CxS	1	69	216	0.006
AxB	AxBxS	1	69	44050	19.05**
AxC	AxCxS	1	69	745	0.160
BxC	BxCxS	1	69	126	0.041
AxBxC	AxBxCxS	1	69	2	0.0005
Between Subjects					
AxD	AxS	2	69	2059	0.629
AxS		69		3276	
BxD	BxS	2	69	7184	2.63
BxS		69		2728	
CxD	CxS	2	69	32750	0.861
CxS		69		38040	
Axis of Rotation (D)	S	2	69	197900	2.22
Subjects (S)		69		89180	
AxBxD	AxBxS	2	69	6721	2.91*
AxBxS		69		2312	
AxCxD	AxCxS	2	69	2442	0.525
AxCxS		69		4646	
BxCxD	BxCxS	2	69	2292	0.746
BxCxS		69		3074	
AxBxCxD	AxBxCxS	2	69	799	0.229
AxBxCxS		69		3487	

* $p < .10$
** $p < .001$

Table 2

Mean reaction times (in msec.) for Experiments I, II and III combined, averaged over the variable "Hand".

Stimulus Position	Spatial Transformation	
	Normal	Rotated
Left Visual Field	608	612
Right Visual Field	593	631

Table 3

Mean reaction times (in msec.) for Experiments I, II, III and IV averaged over the variable "Hand". (N = Normal Orientation, X = rotation around the X axis, Y = rotation around the Y axis, Z = rotation around the Z axis)

Experiment I

	N	Y
Left Visual Field	621	623
Right Visual Field	599	663

Experiment II

	N	X
Left Visual Field	630	639
Right Visual Field	614	649

Experiment III

	N	Z
Left Visual Field	575	575
Right Visual Field	565	582

Experiment IV

	Y	X	Z
Left Visual Field	512	510	519
Right Visual Field	564	551	527

The normal orientation in the right visual field produced the lowest reaction times overall, and the rotated digits in the same field yielded the highest reaction times. In the left visual field the normal orientation was again lower than the rotated form. These rank-orders were consistent for each of the three experiments individually (Table 3) except that the normal and rotated forms gave equal reaction times in the left visual field in Experiment III.

The Position x Orientation x Axis of Rotation (AxBxD) interaction in the combined analysis (Table 1) was marginally significant: $\underline{F}_{2,69}=2.91$, $\underline{p}<.10$. Considering the relatively large number of subjects that were run, it seems reasonable to conclude that all spatial transformations contributed to the overall Position x Orientation interaction (see Figure 4).

The rank order of difficulty of the three types of rotations was: Z-axis of rotation (579 msec.), Y-axis rotation (643 msec.) and X-axis rotation (644 msec.). These rank-orders are in agreement with those found by Kolers and Perkins (1969b) and those of Taylor (1972a).

In the analysis of variance for Experiment IV (Table 4), there were no data for normally oriented digits, which serve as a baseline control condition, and hence the Position x Orientation (AxB) interaction was not the point of interest. The "A" variable, Stimulus Position, was the variable of interest for suggestions of laterality. It was

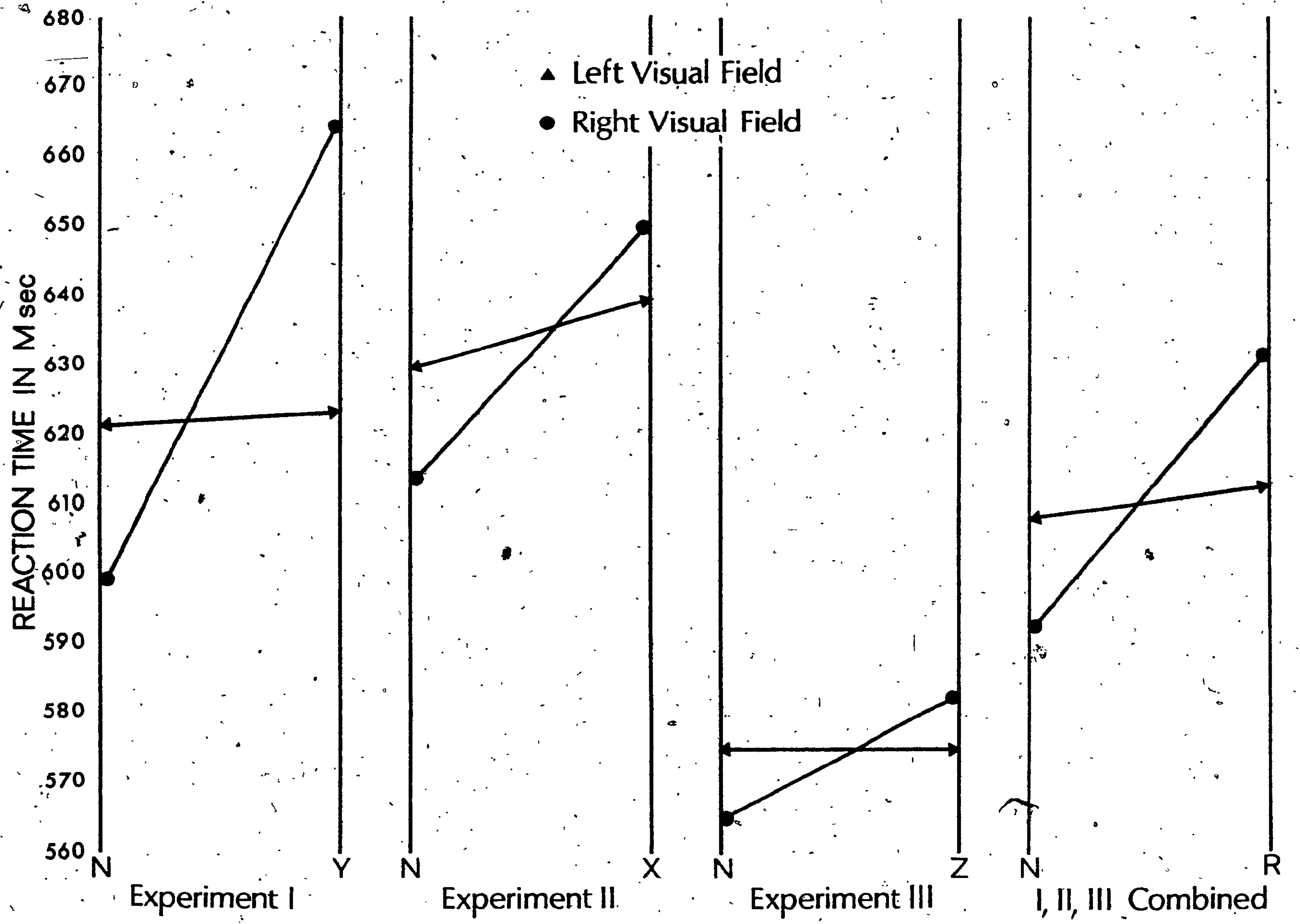

FIGURE 4: Interaction of Stimulus Position X Orientation in Experiments I, II and III separately and combined (N = Normal Orientation, X, Y & Z = Rotations around X, Y & Z axes respectively, R = Rotated).

Table 4

Summary table of analysis of variance for Experiment IV.

Source	Denominator	Degrees of Freedom Num	Den	Mean Square	F Ratio
Stimulus Position (A)	AxS	1	23	41750	13.95*
AxS		23		2993	
Orientation (B)	BxS	2	46	2723	1.20
BxS		46		2268	
AxB	AxBxS	2	46	6213	2.60
AxBxS		46		2386	
Subjects (S)		23		55340	

* $p < .001$

significant, $\underline{F}_{1,23}=13.95$, $\underline{p}<.001$. The Position x Orientation interaction was marginally significant ($\underline{F}_{2,46}=2.60$, $\underline{p}<.10$).

The difference between left and right visual field reaction times for "Z" rotation was 8 msec., while for "Y" and "X" it was 52 and 41 msec., respectively (see Table 4 and Figure 5). This anomoly may be the result of differential practice on "Z". In the analysis of variance comparing Experiments III and IV (Table 5) using the data for the "Z" rotation and right hand only for both experiments, a significant difference was found for the variable of "Experiment". This presumably is the consequence of practice, as subjects had first served in Experiment III, and hence were highly practised on the "Z" rotation and not on the other two rotations. This would decrease the difference between reaction times in left and right visual fields. If the subjects were making their decisions as quickly as possible, then the left visual field value would be the baseline for the rotated stimuli. With practice, subjects can presumably lower their right visual field values to approach those in the left.

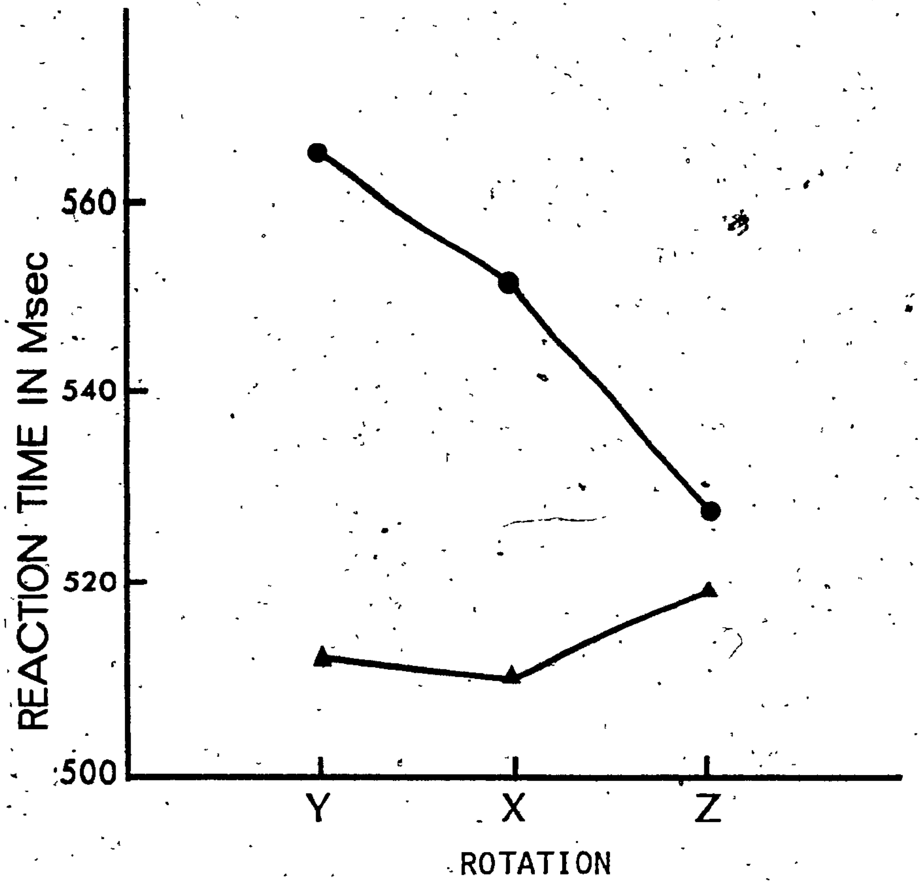

FIGURE 5: Experiment IV mean reaction times, averaged over the variable "Hand".

Table 5

Summary table of analysis of variance comparing Experiments III and IV.

Source	Denominator	Degrees of Freedom Num	Den	Mean Square	F Ratio
Stimulus Position (A)	AxS	1	23	799	0.293
AxS		23		2732	
Experiment (B)	BxS	1	23	93810	15.11
BxS		23		6207	
AxB	AxBxS	1	23	184	0.099
AxBxS		23		1866	
Subjects (S)		23		37590	

DISCUSSION

The main outcome of this series of experiments is the finding of significant differences between reaction times of normal and rotated forms in the right visual field and no such differences in the left visual field (i.e., the Stimulus Position x Orientation interaction). Because anatomical pathways from each visual field lead solely to the contralateral cerebral hemisphere, the interaction can be interpreted as a laterality effect. This is simply to say that the two hemispheres differ in their processing for this task.

In order to explain the relative efficiencies of the two hemispheres and the two types of stimuli, different processing strategies must be suggested. There are several possibilities, a few of which are suggested here.

One such possibility is that the left hemisphere is specialized for recognition of figures shown in their familiar orientation. Therefore, when the digits are less familiar, as with the rotated figures here, the left hemisphere is relatively inefficient. However, in the right hemisphere, the rotated digit was generally as easily recognized as a non-rotated digit. This suggests that the right hemisphere is performing an analysis on orientation-free criteria, such as those of a pure shape comparison.

Shepard and Metzler (1971) had subjects compare a three-dimensional stimulus to a previously presented one in a same-different reaction time task in a nondivided visual field. The stimuli were rotated with respect to each other, rotations ranging from 0° to 180° in gradations of 20°. They obtained an increasing linear gradient when they plotted reaction time against angular difference between the two forms. They suggested that the subjects were "mentally rotating" one of the figures to the orientation of the other in order to compare them. It is conceivable that something like this may be going on in the left hemisphere. It would presumably take more time to compare digits after performing a "mental rotation" than if they could be compared without this step on the basis of pure shape criteria. Again, it is suggested that a shape analysis may be occurring in the right hemisphere.

It is also possible, as already mentioned, that the added latency for the rotated digits in the right visual field reflects the extra time taken for a callosal transmission of information. Perhaps even when the test digit appears in the right visual field the right cortex processes the actual comparison because of a relative proficiency for this type of task. Taylor (1972a) suggests that the normalization of symbols could be a right hemisphere function.

For the present study it cannot be said whether the differences lie in perceptual coding or in memory. It is possible that the left hemisphere stores the symbols in their normal orientation, but the right has some sort of coding such that the features of the shape are stored with less dependence on orientational attributes.

In this study, the lateral mirror-image stimulus did not prove to be significantly different from other mirror-images. This does not provide support for the notion that lateral mirror-images are processed differently from upside-down ones. The findings do not contradict the argument that the corpus callosum reverses stimuli laterally, but it is not the most parsimonious explanation for the results. However, this study is not directly comparable in stimuli or task requirements to others which have shown lateral mirror-image difficulties. Furthermore, the situation is radically different from the interocular transfer studies using animals.

In many studies using mirror-image and human subjects, the task has been to compare orientations of the stimulus pairs, whether in successive presentations (e.g., Butler, 1964; Over and Over, 1967) or in simultaneous presentations (Sekuler and Houlihan, 1969). In these experiments the situation requiring a "same" judgment requires identical shapes in identical orientations, whereas "different" judgments require identical shapes, one being a mirror-image of the other. This is quite different from the present study where orientation is ignored and the identity of the shapes is in question. In a task such as the latter, the lateral mirror-image has not produced more errors or longer reaction times than upside-down mirror-images (Kolers and

Perkins, 1969a, b; Taylor, 1972a). However, in studies using the former methodology, the lateral mirror-image has yielded greater reaction times and more errors. It may be more difficult to label orientation in the lateral mirror-image case than with other mirror-images, but this may not mean that the recognition of these shapes is impaired relative to the upside-down forms.

The suggestion of laterality in processing mirror-image stimuli is especially interesting considering the early (e.g., Orton) theories of dyslexia as being caused by "mixed laterality". The results reported here suggest that the right hemisphere might perhaps confuse a stimulus and its mirror-image, the actual shape being important, with orientation (at least in memory) being of subordinate importance. However, this argument applies to all mirror-images, and not merely lateral mirror-images; following this argument the upside-down confusions should occur as frequently as do the lateral confusions, and in fact this is not the case with dyslexics (Frith, 1970).

Because the variable "Hand" was not significant in main effect nor in interaction with any other variables in this study, there can be no suggestions made as to which hemisphere processed the actual decision in the task. It would seem that each hemisphere can direct each hand's movement equally quickly, or that the hands' responses were controlled subcortically (Myers, 1965) and not subject to lateral differences in this type of task. These results are in agreement with those of Davis and Schmidt (1971) and Dimond (1970), who also found no significant effects with "Hand". It contradicts the findings of other investigators who did find Hand x Visual Field interactions (Berlucchi, Heron, Hyman, Rizzolatti and Umilta, 1971; Jeeves and Dixon, 1970; Umilta, Frost and Hyman, 1971). All of these investigators found the fastest reaction times with ipsilateral hand-hemisphere combinations.

In summary, the present study suggests that there is a laterality effect in visual processing of orientation, based on the Stimulus Position x Orientation interaction. No firm predictions could be made on the basis of the variable "Hand". Speculations were made as to differential processing strategies which might cause laterality effects.

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Appendix A

Instructions

During a trial you will first see two adjacent digits in the centre of the screen. The rightmost one will go away and the other will stay; following this a digit will reappear on either side of the remaining digit. Your task is to decide whether it is the same number as that which disappeared or another number entirely. For instance, in the beginning a "52" might appear. Then the "2" would go away. In the case in which YES is the correct response, the reappearing digit must be a "2" --- there could be a "2 5" or a "5 2" on the screen. For a trial in which NO is the correct response, the reappearing digit must be something other than a "2", for example a "7", such that "7 5" or "5 7" might be presented. Sometimes a returning digit will be a mirror-reversed digit*. That does not matter: a seven is still a seven whether it is reversed** or not.

The reappearing digit can return either to the right or to the left of the digit which remains throughout the trial. This remaining digit is the halfway point between the two possible locations of the reappearing digit. Please look straight at this centred digit throughout the trial. In the first example given the "2" can return either to the right or to the left of the "5". You would be looking directly at the "5".

You will indicate your decision by pressing one of two buttons. You will use only one hand during any one session. The experimenter will point out which is the YES and which is the NO button and how to rest your fingers on the buttons.

The computer will actually run this experiment, and will select the digits you see during a session, as well as randomizing the trials so that YES and NO are correct each an average of 50% of the time. The computer will also tell you when you have made a mistake: a large "X" will appear immediately in the centre of the screen.

There are two ways to make a mistake: by pressing the wrong button or by taking too long to decide which button to press. The computer will be timing you to see how long it takes you to press a button correctly on each trial. If you make a correct response, then your time will be shown in the lower left-hand corner of the screen. For example, you might see "0960", which means 960 milliseconds, or .96 seconds.

You are the one to decide when you want each trial to begin. To signal the computer that you are ready, simply press both buttons. You may do this immediately after making a response to the stimuli or later. If you wait, a flashing line will be shown in the lower left-hand portion of the screen to tell you that the computer is ready any time that you are.

* For Experiments II and III this read: "upside down digit" and for Experiment IV it read: "either a mirror-reversed or an upside down digit".

** For Experiments II and III this read: "upside down" For Experiment IV it read: "changed in orientation".

Appendix B

Table 1

Mean reaction times in msec. for individual subjects in Experiment I. (LVF = Left Visual Field, RVF = Right Visual Field, N = Normal Orientation, Y = rotation around the Y axis)

	Left Hand				Right Hand			
Subject Number	LVF		RVF		LVF		RVF	
	N	Y	N	Y	N	Y	N	Y
1	577	585	565	558	751	671	639	611
2	451	464	459	538	624	637	617	645
3	723	855	570	566	622	670	534	698
4	491	454	451	485	591	477	576	671
5	793	588	808	781	675	839	757	902
6	473	485	450	470	533	547	520	656
7	562	569	545	561	568	635	570	703
8	704	885	775	1027	821	814	767	835
9	481	442	453	456	564	586	509	599
10	463	477	463	566	419	451	422	468
11	494	537	477	467	569	528	553	572
12	902	792	805	977	621	685	647	688
13	674	514	606	706	444	431	445	441
14	586	697	513	569	482	568	483	636
15	576	576	613	611	603	507	736	626
16	564	583	491	577	673	688	786	745
17	858	853	700	851	574	632	567	579
18	803	707	646	790	529	503	624	603
19	694	768	781	709	634	650	491	590
20	812	858	775	1113	727	606	759	747
21	806	847	878	1068	625	617	516	613
22	473	514	371	493	590	527	490	541
23	762	764	766	792	669	636	646	705
24	521	562	541	614	644	619	601	614
Overall Mean	635	640	604	681	606	605	594	645

Appendix B

Table 2

Mean reaction times in msec. for individual subjects in Experiment II. (LVF = Left Visual Field, RVF = Right Visual Field, N = Normal Orientation, X = rotation around the X axis)

	Left Hand				Right Hand			
Subject Number	LVF		RVF		LVF		RVF	
	N	X	N	X	N	X	N	X
1	630	482	684	641	780	683	626	761
2	665	589	597	523	486	465	519	527
3	556	622	612	631	779	777	736	965
4	691	553	715	795	620	646	660	754
5	438	459	422	409	891	1028	836	871
6	663	693	746	707	667	708	661	685
7	583	530	499	549	565	533	595	527
8	662	709	578	611	649	610	671	680
9	618	570	538	564	600	604	622	646
10	514	532	485	519	556	552	570	539
11	852	743	726	880	570	558	545	515
12	578	635	560	668	688	730	661	851
13	633	813	804	714	607	634	547	645
14	463	484	436	464	408	423	409	414
15	440	436	426	414	488	440	434	453
16	829	840	761	792	672	723	678	814
17	612	639	627	741	513	579	539	604
18	432	457	466	504	506	489	509	421
19	508	639	582	649	862	942	832	914
20	836	989	746	633	737	695	811	865
21	821	833	666	741	788	697	672	710
22	749	651	646	799	581	683	602	495
23	361	436	422	429	425	568	431	390
24	746	851	652	784	900	803	921	931
Overall Mean	639	645	629	666	620	632	600	632

Appendix B

Table 3

Mean reaction times in msec. for individual subjects in Experiment III. (LVF = Left Visual Field, RVF = Right Visual Field, N = Normal Orientation, Z = rotation around Z axis)

Subject Number	Left Hand				Right Hand			
	LVF		RVF		LVF		RVF	
	N	Z	N	Z	N	Z	N	Z
1	761	872	752	840	667	678	748	829
2	722	540	622	656	543	598	562	635
3	577	538	576	546	691	642	543	567
4	485	486	514	504	601	571	537	651
5	409	473	431	415	448	412	419	469
6	664	597	662	687	780	744	681	568
7	421	403	489	457	425	450	392	452
8	742	798	805	778	577	605	568	633
9	359	325	396	396	481	547	519	617
10	531	578	505	462	397	333	381	398
11	520	478	507	493	604	746	675	613
12	825	724	706	786	759	730	782	721
13	515	503	481	530	641	635	640	727
14	555	477	568	611	657	562	493	491
15	984	694	724	804	559	572	582	553
16	540	744	602	635	560	527	592	549
17	579	608	601	603	554	552	533	535
18	430	434	436	423	528	515	534	636
19	533	521	443	476	781	805	863	817
20	475	512	543	536	520	620	536	532
21	481	541	608	524	463	476	380	460
22	589	601	539	682	741	754	649	706
23	590	703	696	513	509	511	495	507
24	405	432	410	511	423	429	393	420
Overall Mean	571	566	567	578	580	584	562	587

Appendix B

Table 4

Mean reaction times in msec. for individual subjects in Experiment IV. (LVF = Left Visual Field, RVF = Right Visual Field, Y = rotation around the Y axis, X = rotation around the X axis, Z = rotation around the Z axis)

Right Hand						
Subject Number	LVF			RVF		
	Y	X	Z	Y	X	Z
1	633	503	562	725	611	612
2	448	514	533	536	534	538
3	514	543	582	708	631	632
4	434	470	530	546	547	445
5	488	399	491	486	504	444
6	650	562	516	449	677	460
7	402	475	480	433	411	376
8	865	628	693	786	700	724
9	340	414	297	369	364	428
10	361	337	345	403	377	336
11	519	491	605	543	517	510
12	573	608	624	874	755	646
13	486	511	502	547	539	527
14	506	496	485	529	488	505
15	525	591	545	612	681	573
16	477	535	507	568	589	556
17	486	517	468	503	531	529
18	373	400	412	471	443	408
19	676	684	734	784	674	710
20	518	503	488	524	518	530
21	589	584	649	572	628	671
22	506	485	513	661	548	515
23	512	522	457	438	512	550
24	403	464	429	471	450	427
Overall Mean	512	510	519	564	551	527

Appendix C

Table 1

Summary table of analysis of variance for Experiment I.

Source	Denominator	Degrees of Freedom Num	Den	Mean Square	F Ratio
Stimulus Position (A)	AxS	1	23	4153	0.787
AxS	—	23		5280	
Orientation (B)	BxS	1	23	52770	15.92*
BxS		23		3317	
Hand (C)	CxS	1	23	36440	0.993
CxS		23		844200	
AxB	AxBxS	1	23	46040	27.45*
AxBxS		23		1677	
AxC	AxCxS	1	23	1013	0.230
AxCxS		23		4401	
BxC	BxCxS	1	23	3112	0.616
BxCxS		23		5048	
AxBxC	AxBxCxS	1	23	1059	0.367
AxBxCxS		23		2884	
Subjects (S)		23		86865	

* $p < .001$

Appendix C

Table 2

Summary table of analysis of variance for Experiment II.

Source	Denominator	Degrees of Freedom Num	Den	Mean Square	F Ratio
Stimulus Position (A)	AxS	1	23	331	0.109
AxS		23		3042	
Orientation (B)	BxS	1	23	22790	8.03*
BxS		23		2838	
Hand (C)	CxS	1	23	26370	0.586
CxS		23		44962	
AxB	AxBxS	1	23	7727	2.94
AxBxS		23		2640	
AxC	AxCxS	1	23	3040	0.530
AxCxS		23		5706	
BxC	BxCxS	1	23	12	0.006
BxCxS		23		2103	
AxBxC	AxBxCxS	1	23	463	0.116
AxBxCxS		23		3999	
Subjects (S)		23		101700	

* p <.01

Appendix C

Table 3

Summary table of analysis of variance for Experiment III.

Source	Denominator	Degrees of Freedom Num	Degrees of Freedom Den	Mean Square	F Ratio
Stimulus Position (A)	AxS	1	23	88	0.058
AxS		23		1508	
Orientation (B)	BxS	1	23	3640	1.788
BxS		23		2035	
Hand (C)	CxS	1	23	2914	0.090
CxS		23		32450	
AxB	AxBxS	1	23	3728	1.423
AxBxS		23		2619	
AxC	AxCxS	1	23	1576	0.412
AxCxS		23		3827	
BxC	BxCxS	1	23	1587	0.767
BxCxS		23		2068	
AxBxC	AxBxCxS	1	23	76	0.022
AxBxCxS		23		3575	