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Visual Field Effects in Mental Rotations

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Summary

Thirty seven subjects were tested on a mental rotation task which has previously shown visual half-field effects. The test employed two-dimensional figures and required keyboard responses after presentation of objects to both visual fields. Subjects were classified either as "right-rotators" or "left-rotators" on the basis of responses in a pencil-and-paper visual mental rotation test. All subjects showed a reliable mental rotation effect, i.e., the amount of time required to give correct responses correlated with the number of degrees of rotation. Statistically insignificant effects were found in the expected direction for hemisphere effects. The trends were opposite in the left- and right-rotator groups. There was no indication of better performance for clockwise or counterclockwise rotations in separate visual fields.

Key words: mental rotation, laterality, cerebral hemispheres, tachistoscope, reaction times

Introduction

Clinical neurology has long indicated functional differences between the cerebral hemispheres in Man. Since the 1960s, techniques for elucidating these differences in normal subjects have been devised and led to a massive "laterality" literature. The focus of most such research has been on demonstrating the nature and magnitude of hemispheric differences, but more recent efforts have been devoted asking questions about hemispheric interactions. Hellige (1990) has outlined three distinct approaches to questions of interactions, which he labels "cooperative collaboration", "cross-hemispheric integration", and "metacontrol".

The present study was designed to delineate hemispheric interactions of the cooperative type. The basic technique is to present information briefly to both visual half-fields, in a task which requires the information on ***both*** sides to be used for correct responses. By changing the nature of the information presented to one side or the other, specific questions about the kind of information each hemisphere handles best can be answered.

Methods

The experiments were run on a Macintosh IIci computer with screen refresh rates of 17 msecs. Stimuli were presented for 150 msecs following a one second fixation dot. Subjects were required to respond "same" when the geometrical objects appearing in the left visual field (LVF) and right visual field (RVF) were the same or could be rotated (in the plane of the screen) to become the same. "Different" responses were obtained when no rotation could allow identity. Subjects responded on the keyboard with both hands to all stimuli - index fingers for "same" and forefingers for "different". Correct and incorrect responses and response times for both hands were recorded, but left-right differences were always small and were not analyzed. For analysis, the faster of the two responses was used.

Subjects included 13 men and 24 women between the ages of 19 and 44. All subjects answered an abbreviated form of the Edinburgh handedness test and were grouped as either strongly right-handed (33 subjects) or left-handed/ambidextrous (4 subjects). Prior to the tachistoscopic testing, all subjects were tested on a 12-item paper-and-pencil mental rotation task. This served to explain the subsequent tachistoscopic task and to give the subjects some practice with mental rotation. Following the tachistoscopic test, the subjects were required to go through the same 12 items and to indicate the way in which they obtained their answers. These responses were used to classify the subjects as either left-rotators or right-rotators.

In the pencil-and-paper test, subjects were asked which of the two geometrical objects they rotated in order to make their same/different judgment. As shown in Figure 1, both objects were presented askew, with the major axes not lying on the vertical or horizontal axes. When such gravitationally stable objects are used, subjects tend to rotate an askew object toward the orientation of a gravitationally stable object, rather than vice versa. When both objects are askew, however, individual differences become apparent. That is, some subjects show a strong preference for rotating the object on the left toward the orientation of that on the right, and others vice versa. A minority of subjects show no preference. A strong correlation with handedness has previously been found (Cook, et al., 1994) - where left-handers prefer to rotate the object on the left and right-handers the object on the right.

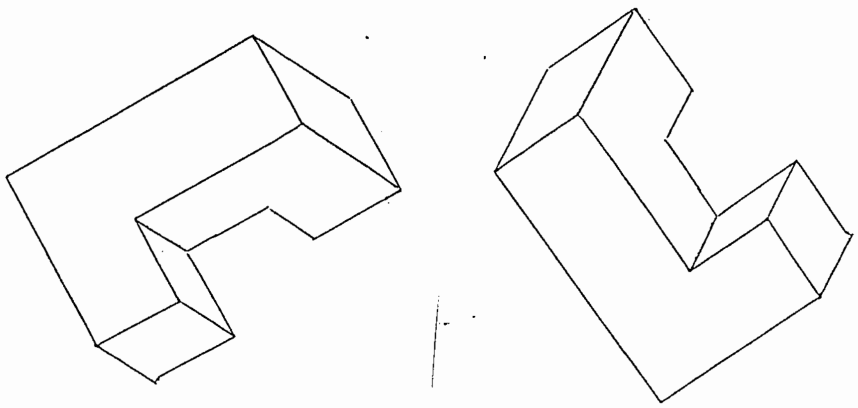

Figure 1: Geometrical objects used in the pencil-and-paper test.

In the tachistoscopic test, there were two conditions of primary interest. These were conditions in which two "same" objects were presented, one of which was in a gravitationally-stable orientation (major axes in the vertical and horizontal directions) and one of which was gravitationally unstable (67.5 or 112.5 degree clockwise or counter-clockwise rotation from stability). Because it is known that subjects will normally rotate an unstable object to the orientation of a gravitationally-stable object (Shepard and Metzler, 1985), it was hypothesized that the best performance on this tachistoscopic test of mental rotation would occur when the preference for rotation from the unstable to the stable orientation was consistent with the subjects preferred direction of rotation when two unstable objects are presented. In other words, if the individual prefers to rotate the right object toward the orientation of the object presented on the left (the "handedness bias"), then if the left-side object is also gravitationally stable, this preference will be strengthened. In contrast, when the handedness bias is in a direction opposite to the gravitational bias, the mental rotation strategy should be less clear and subject responses should be somewhat delayed.

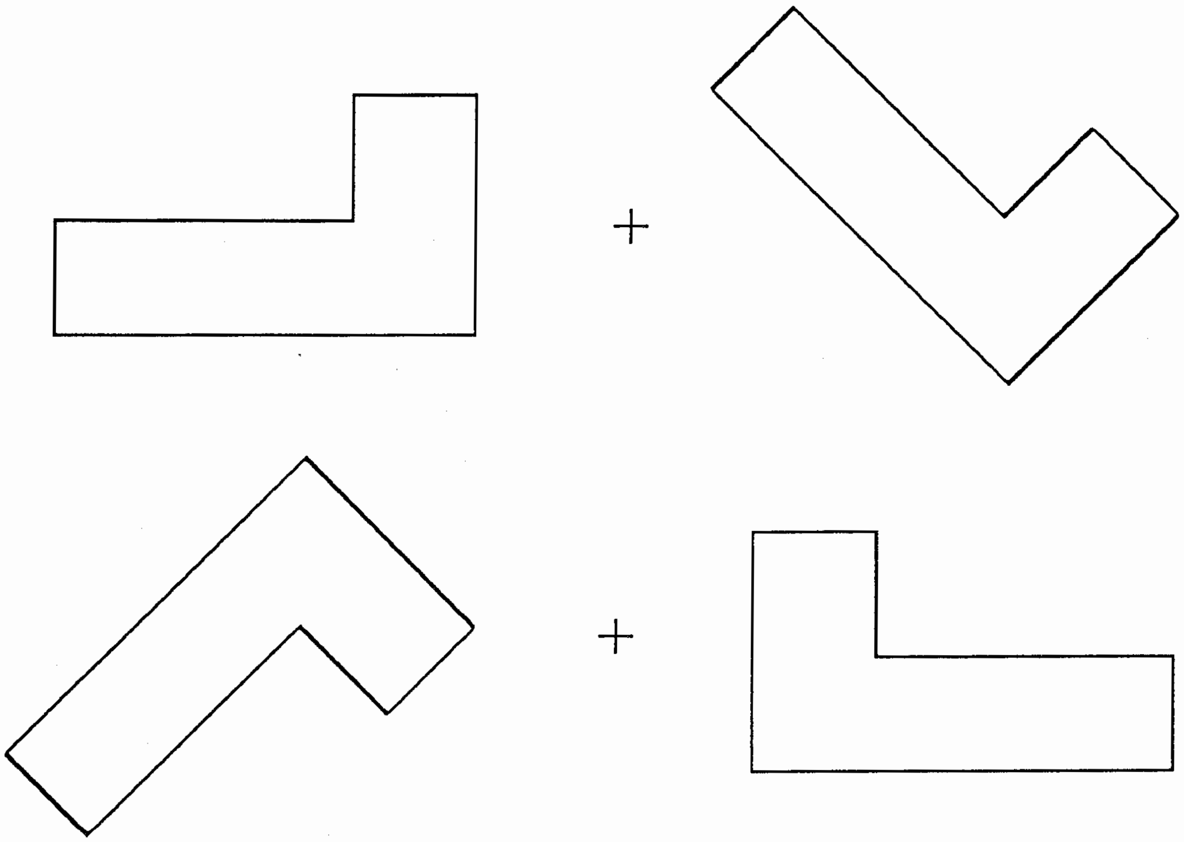

Figure 2: Examples of stimuli in the tachistoscopic test. One object is gravitationally stable, the other is unstable.

Results

As we have previously found (Cook et al., 1994), most subjects (24) showed a consistent preference for rotating the object on the right (21) or left (3) side when both objects are presented in gravitationally unstable orientations. Only 4 showed a consistency of less than 75% to one side or the other. The preference for side of rotation is not strongly related to eye dominance. Of the 24 subjects reporting consistent (100%) right-rotations, 7 reported a dominant left eye (29%). Of the 9 subjects reporting predominantly left-rotations, 5 reported left eye dominance (56%).

The results of the tachistoscopic test were analyzed to detect three separate effects. The first is the well-known temporal effect of mental rotation itself: the larger the amount of rotation required to match two objects, the slower is the response time. The second is a laterality effect: two previous studies have reported that clockwise rotations are more quickly performed in the RVF than the LVF, and vice versa for counter-clockwise rotations. Finally, the main topic of this study was the relative response times when a gravitationally stable object is presented to one visual hemisfield, and an unstable object is presented to the other hemifield.

Four-way analysis of variance was done. Factors were (A) rotation bias (self-report of tendency to rotate the object on the left or rightin the pencil-and-paper test), (B) degrees of rotation (0, 67.5 and 112.5 degrees), (C) direction of rotation (clockwise vs. couter-clockwise) and (D) side of gravitational stability (left or right). No interactions were significant, and only the "degrees of rotation" factor was significant on its own (F=32.425, p=.0001).

The largest effect was the well-known time-dependence of mental rotation dependent on degrees of rotation. Ignoring factors of direction of rotation and the side on which a stable or unstable figure was presented, a strong mental rotation effect was found. When only a matching was required, responses were fastest (946 msecs), and were linearly slower with increasing rotation (1288 msec at 67 degrees, and 1604 at 113 degrees). These values were all significantly different from one another (p<.0001 in all combinations). From them a speed of mental rotation of 171 degrees per second can be calculated, typical of values reported in the literature (Shepard and Cooper, 1982).

A comparison of the clockwise/counter-clockwise direction of rotation (regardless of the stability/instability factor) showed opposite and insignificant trends for the 67 and 113 degress rotation cases (1275 and 1612 msecs vs. 1317 and 1582 msecs). There were virtually no differences in the number of correct responses according to the direction of rotation. These results suggest that there is no visual field/direction of rotation effect, contrary to previous reports (e.g., Corballis and Sergent, 1989).

A comparison of the hemifield effect regarding stability/instability (regardless of the clockwise/counter-clockwise direction of the rotation) showed faster rotations when the stable figure was on the left (1271 and 1579 msecs at 45 and 135 degress) than when it was on the right (1320 and 1614 msecs, respectively). Although those effects were not statistically significant, it is of interest that the reverse effects were found in the "left rotator" group. That is, analysis of the results from the 9 "left rotators" showed the expected reversal of speed advantage found in right-rotators.

The left-rotators (n=9) had slightly faster responses when the stable object was on the right side (1374 msec) than the left side

(1441 msec), but the effect was not statistically significant (p=0.15). Right-rotators showed the opposite trend (1475 vs 1446 msec), but not significantly. The left-rotators rotated more quickly when clockwise rotation (1387 msec) was required than when a counter-clockwise rotation (1424 msec) was required. In contrast, the right-rotators were quicker with counter-clockwise rotations (1425 msec) than clockwise rotations (1492 msec). None of these effects were significant. The fact that left-rotators and right-rotators showed opposite trends suggests that the grouping of subjects on this basis in mental rotation experiments may be important, but the present effects were statistically weak.

Discussion

The results of the pencil-and-paper test confirmed previous findings that most subjects have a strong tendency to rotate the object on one side or the other when neither object is "veridical", i.e., gravitationally stable. The significance of that finding with regard to hemisphere functions is of course not clear solely on the basis of such a test, but the test does constitute a "non-manual handedness measure", which may prove useful in other contexts.

The tachistoscopic test results confirmed three previous findings, but statistical significance was weak. The strongest effect was the mental rotation effect itself. As Shepard and Metzler (1972) first reported, the amount of time required for a correct response correlates strongly with the number of degrees required to put the two objects into the same orientation. This effect is not found for "different" responses. Generally, "different" responses are much slower than "same" responses, but the amount of rotation has little effect on response times. This can be understood by the fact that there is no definite amount of rotation required for correct "different" responses. Even when the main axis of an L-shaped figure is only 45 degrees from the main axis of a backwards-L, failure to match after 45 degrees is often followed by 135 degree rotation. For this reason, "different" responses are not normally analyzed in mental rotation experiments.

A weaker effect concerns the relative time required when a gravitationally stable object is on one side and an unstable object on the other, and vice versa. We have previously found a stronger effect in two tests, one using the same shape stimuli and 100 msec presentation and the other using more complex 3D figures and 150 msec presentation. The present experiment used again the simplified 2D objects and a longer presentation time.

Methodological Issues

The results of the present experiment were less clear than expected and less robust than two previous experiments of a related kind. This was due, at least partially, to several methodological problems which should be addressed in future work. The most important was the 2D simplification of the geometrical objects. Instead of increasing the reliability of the results, the simplified figures led to simplified, non-rotational strategies, at least according to the reports of several individuals. Specifically, some subjects reported a strategy of identifying each figure separately as an "L" or as a "backwards-L", rather than performing mental rotation. This possibility can and should be eliminated by using 3D objects which cannot be so easily encoded in a symbolic form. Moreover, a strategy of actively using mental rotation should be explicitly requested to avoid collecting responses which involve other strategies.

Some subjects showed a surprisingly poor level of performance. This could be improved by means of more practice trials and/or repetition of trials which were not correctly performed during the actual test. Both techniques would lead to longer test sessions, but would give results which are statistically stronger.

The present experiment included both same and different trials, which requiredg no mental rotation. That is, there were trials where identical figures were presented at the same orientation or non-identical figures with the same main axes. These conditions were considered essential for making comparisons of evoked potentials in a mental rotation task planned for the future. That is, a "non-rotation-same" matching condition was required for comparison with trials requiring rotation in order to distinguish between brain electrical activity due to rotation and that due specifically to the matching. Addition of these conditions, however, provides no new behavioral information and serves only to prolong the test session.

Finally, a relatively large number of women were subjects in the experiment. Although sex differences in mental rotation have not previously been reported, it is well-known that women show weaker laterality effects. In fact, most of the subjects showing poor performance on the mental rotation task were women and there were fewer women than men who showed strong intra-individual effects. Despite the fact that reliable visual field effects using female subjects have previously been obtained, it may be wise to use only male subjects at least during the development stage..

General Discussion

The present experiments on mental rotation were motivated by a model of hemispheric "dominance" which emphasizes the importance of the "manipulation" role of the LH. Although a variety of hemispheric specializations have been reported in clinical patients and normal subjects, none have the strength and consistency which are known to be associated with (i) handedness and (ii) speech production. Since both speech and handedness are fundamentally the ***expression*** of control center information, the hypothesis is that the LH is specialized for the active manipulation (sequentialization) of information, while the RH handles comparable information, but is not specialized for its sequential expression. Since mental rotation is known to have a sequential time-dependent character, it may be more easily performed by the LH, and indeed brain-damage studies indicate this to be the case (Mehta et al., 1987).

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