Bulletin of the Psychonomic Society
1989, 27 (1), 25-28

No hemispheric differences for mental rotation of letters or polygons

WILLIAM COHEN
University of California, San Diego, California

and

JOHN POLICH
Scripps Clinic, La Jolla, California

Hemispheric effects for mental rotation were assessed with letters and polygons presented in their normal or mirror-image form at various degrees of rotation from upright to the center, left, and right visual fields. Mean reaction times and error rates for center-field processing were shorter than for those for either the left or right visual-field presentations. No evidence was found of any hemispheric differences for either the letter (verbal) or polygon (spatial) stimuli. These results suggest that the cognitive processes underlying mental rotation are not hemisphere-specific.

Despite a large number of studies using mental rotation paradigms (Cooper, 1975; Shepard & Metzler, 1971) to explore biological variables relevant to the cognitive operations underlying observed reaction-time data (e.g., Childs & Polich, 1979; Kail, 1985; Kershner, 1979; Lohman, 1986; Tapley & Bryden, 1977), the neuropsychological locus of the mental rotation effects remains unclear. Some neurophysiological evidence for superior right-hemisphere (RH) mental rotation processing has been reported for lesion studies of humans who have suffered exclusive left- or right-hemispheric damage: When required to mentally rotate manikin pictures or three-dimensional landscape scenes, subjects with RH damage performed more poorly than did subjects with left-hemisphere (LH) damage (Butters & Barton, 1970; Kim, Morrow, Passafiume, & Boller, 1984; Ratcliff, 1979). However, other lesion data suggest that both hemispheres can contribute to the performance of these tasks when stimuli are complex (Butters, Barton, & Brody, 1970; De Renzi, 1978; Kim et al., 1984). Electroencephalographic recordings from normal individuals asked to rotate three-dimensional cube shapes (Shepard & Metzler, 1971) produced greater RH activity than did control conditions, but only at specific measurement sites (Ornstein, Johnstone, Herron, & Swencionis, 1980; Papanicolaou et al., 1987). Additional reports assessing complex visuospatial performance with these techniques have not obtained strong RH effects (Galin, Johnstone, & Herron, 1978; Gevins et al., 1979).

This research was supported by NIAAA Grant AA06420 and is Publication 5051BCR from the Research Institute of Scripps Clinic. This work was the first author's undergraduate Honor's Thesis. We thank Ebbe Ebbesen for his administrative support and Don MacLeod for comments. Correspondence may be addressed to J. Polich, Preclinical Neuroscience (BCR1), Scripps Clinic and Research Foundation, 10666 N. Torrey Pines Rd., La Jolla, CA 92037.

A similar lack of consistency for the lateralization of hemispheric differences for mental rotation tasks also has been reported for behavioral measures. Several mental rotation investigations using reaction time and performance accuracy have demonstrated that the RH was faster and/or more accurate than the LH when either letters or geometric forms were employed as stimuli, although only when the angle of rotation from normal was relatively large (Cohen, 1975; Jones & Anuza, 1982). Additional studies have shown that, under some conditions, mental rotation was carried out in the LH more accurately than in the RH, with letters and three-dimensional cube shapes as stimuli (Corballis, Macadie, & Beale, 1985; McGuinness & Bartell, 1982; Ornstein et al., 1980). When mental rotation techniques have been combined with stimulus matching procedures, an RH advantage for letter stimuli and an LH advantage for nonsense line figures have been reported (Fischer & Pellegrino, 1988; Simion, Bagnara, Bisiacchi, Roncato, & Umiltà, 1980). Taken together, these variegated findings suggest that mental rotation may not engage only an RH or LH neuropsychological process. Rather, each hemisphere may contribute to mental rotation effects depending on the exigencies of the stimulus materials, task parameters, and subject populations, as have been found with other laterality paradigms (e.g., Hellige, Corwin, & Jonsson, 1984; Moscovitch, Scullion, & Christie, 1976; Polich, 1986).

Because of these difficulties, the present study was undertaken to provide a straightforward and comprehensive assessment of hemispheric differences for mental rotation processes. First, both verbal (letters) and spatial (polygons) stimuli were assessed within the same group of subjects to determine whether the overall type of stimulus materials would contribute significantly to mental rotation laterality patterns. Second, the canonical "normal versus mirror-reversed" judgment task was used to ensure maximum similarity to previous center-field paradigms. Third, a comparatively large sample of right-handed males was employed in order to maximize hemispheric processing differences. Thus, if mental rotation processes for verbal and spatial stimuli are localized to one or the other hemisphere, any reasonably consistent laterality differences should be detected with the application of classic mental rotation procedures to a hemispherically well-differentiated subject population.

METHOD

Subjects

A total of 24 male subjects (18–24 years of age) were obtained from undergraduate psychology courses at the University of California, San Diego. All subjects were strongly right-handed as assessed by a brief questionnaire (Bryden, 1977) and were screened for vision problems, learning deficits, and neurological insult. The subjects were given course credit or were paid for their participation.

Apparatus and Stimuli

Stimuli were presented on a Gerbrands three-channel tachistoscope linked to an IBM/XT computer that recorded response selection and reaction time for each stimulus condition. The subjects responded by pressing one of two microswitches mounted in a hand-held box that was linked to the computer. The stimuli were the four letters F, G, J, R and four polygons, as illustrated in Figure 1. Each letter or figure was presented in its normal or mirror-image form and subtended a visual angle of 2.8°. The stimuli were presented to either the center visual field (CVF), the right visual field/left hemisphere (RVF/LH), or the left visual field/right hemisphere (LVF/RH). Lateral presentations were made with the center of the stimulus projected 2.8° to the right or left of fixation. Each stimulus also was rotated from upright in a clockwise direction at either 0°, 60°, 120°, or 180°, and presented in its normal or mirror-reversed form at each degree of rotation. Hence, the total number of presentations for both the letter condition and the polygon condition was 96, excluding practice and training trials.

Design and Procedure

One half of the subjects received the letters condition first and one half received the polygons condition first, with half of each group responding "normal" and half responding "reversed" with the right hand. Each subject read an instruction sheet that explained the nature of the stimuli, response requirements, and rest periods. The experimenter reiterated these instructions and stressed that, while speed was important, accuracy was essential. For both conditions, study cards, which consisted of each stimulus shown in its normal and mirrored upright form, were constructed. The subject studied the cards to learn which form of the letters and polygons was normal and which was reversed.

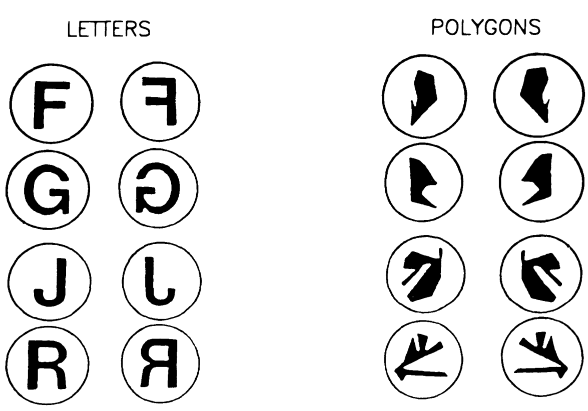

Figure 1. Stimulus materials for the letter and polygon items presented in upright normal and reversed conditions.

Each subject was allowed to view the cards any time throughout the experiment.

Although the letter and polygon conditions were presented separately, they employed the same procedures. First, a training phase occurred in which the four different stimuli were presented tachistoscopically as upright in both their normal and mirror forms in the CVF to provide an introduction to the task situation with the simple examples. Each training-trial block, consisting of eight trials, was ended when the subject completed two consecutive trial blocks without error. The practice phase consisted of 24 trials with six examples of each stimulus shown at randomly selected orientations and in any visual field. This procedure acquainted the subjects with some of the more demanding aspects of the task and facilitated accurate responding at the beginning of the testing phase. Next, the testing phase occurred, wherein each stimulus in each visual field and every orientation was presented randomly. During the practice and testing phases, feedback was given only for incorrect responses. If the subject requested, the stimulus to an incorrect response could be viewed and studied.

The following sequence of events occurred on each trial: The experimenter said "ready," and, approximately 1 sec later, the subject saw a blank white screen for 2,000 msec, followed by a red dot in the middle of a white screen for 1,500 msec. The stimulus then was presented for 100 msec, followed by a blank white screen. After 1,000 msec, the field became dark. The subjects responded with a buttonpress that indicated either a *normal* or *reversed* judgment. Rest periods were provided between stimulus conditions and when requested. At the completion of the experiment, the subject was debriefed about the nature of the study and possible results.

RESULTS

The reaction times (RTs) from the four different stimuli presented at the same degree of rotation and in the same visual field were used to compute the mean correct RT for those conditions for each subject. The overall percent error (PE) was computed from the percentage of incorrect responses from each of the four stimuli for each subject. Error trials were not included in the calculation of the RT data. Invalid responses were treated as errors and defined as pressing both buttons simultaneously or responding in excess of an arbitrary limit of 3,500 msec following stimulus presentation. Data from the training and 24 practice trials were considered as warm-up and excluded from all statistical analyses.

Reaction Time

The mean RTs from letter and polygon stimuli for each degree of rotation from upright and normal or reversed judgment for each of the three visual-field presentation conditions are illustrated in Figures 2 and 3. A four-factor (stimulus × judgment × visual field × angle of rotation) analysis of variance was performed on the mean RTs from all subjects. This overall analysis demonstrated very strong main effects for stimulus type [$F(1,23) = 54.4$, $p < .001$], judgment [$F(1,23) = 18.8$, $p < .001$], and angle of rotation [$F(3,69) = 73.9$, $p < .001$]. These results indicate that the mental rotation task produced RT patterns in the expected manner, independently of visual field. Thus, subjects took longer to identify polygons than to identify letters, it was easier for them to identify normal stimuli than mirror-image ones, and, as angle of rotation from upright increased, so did RT.

A significant effect for visual field was also found [$F(2,46)=8.12$, $p < .001$]. As expected, the subjects responded faster to stimuli presented to the CVF than to stimulus presentation to either periphery, with the means for the CVF, RVF, and LVF at 1,126, 1,197, and 1,190 msec, respectively. However, when the data from LVF and RVF were analyzed separately to assess any hemispheric interactions, main effects similar to the overall analysis were found for task, judgment, and angular departure, but no main effects or significant interactions emerged for visual-field presentation ($p > .25$ in all cases). Thus, the RH or LH did not process either stimulus type significantly faster than the other for any of the experimental variables.

Percent Error

The PE data from letter and polygon stimuli for each degree of rotation from upright and normal or reversed judgment for each of the visual-field presentation conditions are illustrated in Figures 4 and 5. The PE data was subjected to the same four-factor analysis of variance as were the RT data. Strong effects were found for stimulus type [$F(1,23) = 31.2$, $p < .001$], judgment [$F(1,23) = 4.9$, $p < .05$], and angle of rotation [$F(3,69) = 18.5$, $p < .001$]. An interaction between judgment, visual-field presentation, and angle of rotation from upright also was observed [$F(6,138) = 2.8$, $p < .03$]. In general, the subjects made more errors when identifying polygons as opposed to letters, and fewer errors when identifying normal rather than mirror-image stimuli; PE increased as the angle of rotation increased.

A significant effect for visual field also was observed [$F(2,46) = 3.9$, $p < .05$]. The subjects made fewer errors in response to CVF presentations than to stimulus presentation to either periphery, with the mean error rates for the CVF, RVF, and LVF at 9.7%, 13.0%, and 12.3%, respectively. The RVF and LVF data were analyzed separately to assess any hemispheric interactions.

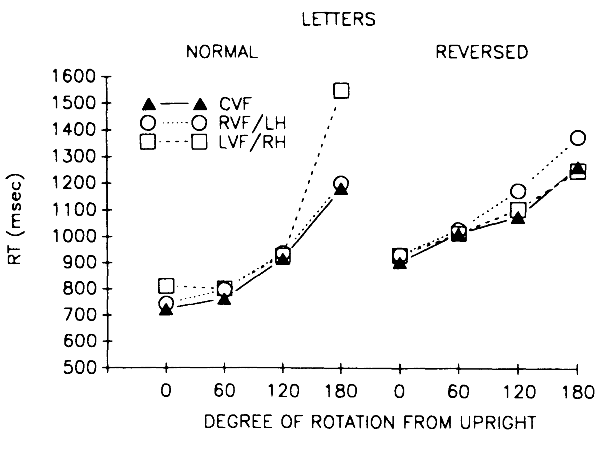

Figure 2. Mean reaction time from the letter stimuli for normal and reversed judgments as a function of degree of rotation from upright for the three visual-field presentation conditions.

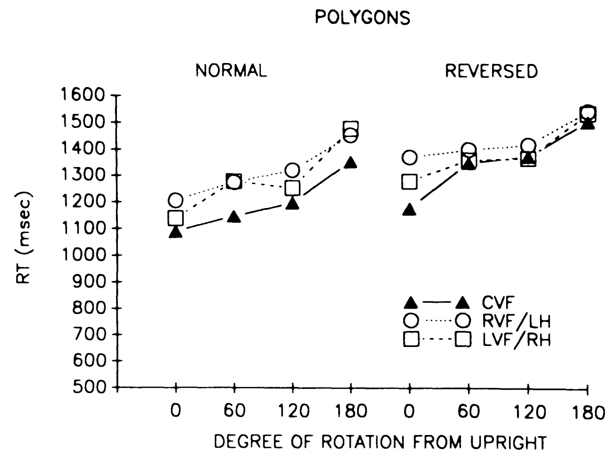

Figure 3. Mean reaction time from the polygon stimuli for normal and reversed judgments as a function of degree of rotation from upright for the three visual-field presentation conditions.

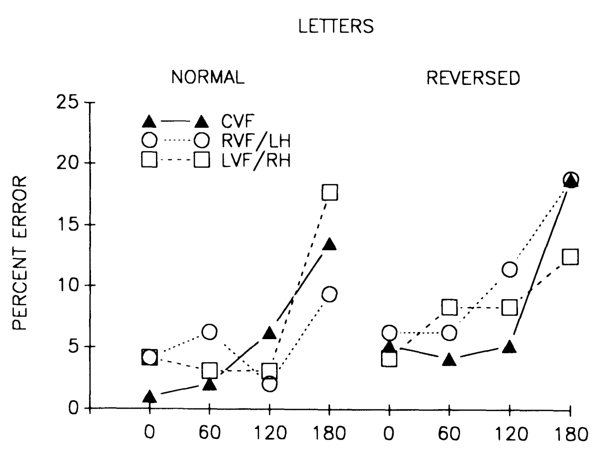

Figure 4. Mean percent error from the letter stimuli for normal and reversed judgments as a function of degree of rotation from upright for the three visual-field presentation conditions.

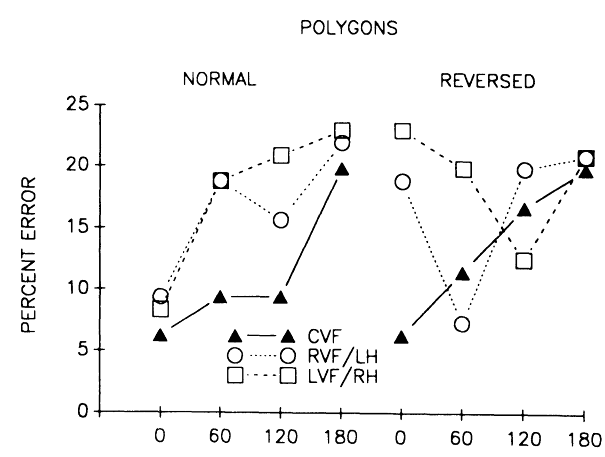

Figure 5. Mean percent error from the polygon stimuli for normal and reversed judgments as a function of degree of rotation from upright for the three visual-field presentation conditions.

Similar main effects as found for the overall analysis were obtained for task, judgment, and angular departure. However, no difference between LH and RH stimulus presentations were observed ($p > .35$ in all cases). The three-way interaction between judgment, visual field, and angle of rotation was significant [$F(3,69) = 4.1$, $p < .03$], but this most likely reflects the wide variability of the PE data between the letter and polygon conditions (see Figures 4 and 5) rather than a meaningful behavioral outcome.

DISCUSSION

A standard mental rotation task applied to explore hemispheric differences yielded results similar to those of previous center-field studies. In general, longer RTs and more PE were observed for stimulus presentations at large rotations from upright (Cooper, 1975; Shepard & Metzler, 1971). However, no significant effects between the RVF/LH and LVF/RH presentations for either the letter or polygon stimuli were obtained. Despite suggestions from previous behavioral mental rotation/hemispheric specialization studies on normals that the RH (Cohen, 1975; Jones & Anuza, 1982; Simion et al., 1980) or LH (Corballis et al., 1985; Fischer & Pellegrino, 1988; McGuinness & Bartell, 1982; Ornstein et al., 1980) may be more effective for the mental rotation of different types of stimuli, no statistically reliable evidence for such a differential efficiency was obtained in the present study.

As illustrated in Figures 2 and 3, the LH was generally more efficient for the letter stimuli, while the RH was generally more efficient for the polygon stimuli. Although these trends are suggestive, they cannot be considered as real because of their weak statistical consistency. These outcomes may represent a failure to reject a null hypothesis that is false (Type II error). However, to counter this possibility, the present study was purposefully designed to maximize the likelihood of obtaining significant hemispheric differences with a comparatively large sample size ($N = 24$) of highly homogeneous (undergraduates) and well-lateralized (strongly right-handed male) subjects. Hence, the experimental conditions employed should have been quite sensitive to laterality effects for this task, although variations on the procedure with other stimulus materials (e.g., a matching paradigm with three-dimensional cube stimuli used in center-field mental rotation studies) may yield more consistent hemispheric differences. Given the lack of reliable laterality results in the present study, it is reasonable to assume that if hemispheric processing differences exist for mental rotation tasks employing letters and polygons as stimuli, they are relatively ephemeral. This outcome supports the conclusion of the variegated findings reported previously: despite the compelling visuospatial nature of the mental rotation paradigm for center-field presentations, task performance appears to employ both LH and RH processes.

REFERENCES

Bryden, M. P. (1977). Measuring handedness with questionnaires. *Neuropsychologia*, **15**, 617-624.

Butters, N., & Barton, M. (1970). Effect of parietal lobe damage on the performance of reversible operations in space. *Neuropsychologia*, **8**, 205-214.

Butters, N., Barton, M., & Brody, B. A. (1970). Role of right parietal lobe in the mediation of crossmodal associations and reversible operations in space. *Cortex*, **49**, 174-190.

Childs, M. K., & Polich, J. M. (1979). Developmental differences in mental rotation. *Journal of Experimental Child Psychology*, **27**, 339-351.

Cohen, G. (1975). Hemispheric differences in the utilization of advance information. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and performance V* (pp. 20-32). London: Academic Press.

Cooper, L. A. (1975). Mental rotation of random two-dimensional shapes. *Cognitive Psychology*, **7**, 20-43.

Corballis, M. C., & Macadie, L., & Beale, I. L. (1985). Mental rotation and visual laterality in normal and reading disabled children. *Cortex*, **21**, 225-236.

De Renzi, E. (1978). Hemispheric asymmetry as evidenced by spatial disorders. In M. Kinsbourne (Ed.), *Asymmetrical function of the brain* (pp. 49-85). New York: Cambridge University Press.

Fischer, S. C., & Pellegrino, J. W. (1988). Hemisphere differences for components of mental rotation. *Brain & Cognition*, **7**, 1-15.

Galin, D., Johnstone, J., & Herron, J. (1978). Effects of task difficulty on EEG measures of cerebral engagement. *Neuropsychologia*, **16**, 461-472.

Gevins, A. S., Zeitlin, G. M., Doyle, J. C., Yingling, C. D., Schaffer, R. E., Callaway, E., & Yeager, C. L. (1979). Electroencephalogram correlates of higher cortical functions. *Science*, **203**, 665-668.

Hellige, J. B., Corwin, W. H., & Jonsson, J. E. (1984). Effects of perceptual quality on the processing of human faces presented to the left and right cerebral hemispheres. *Journal of Experimental Psychology: Human Perception & Performance*, **10**, 90-107.

Jones, B., & Anuza, T. (1982). Effects of sex, handedness, stimulus, and visual field on "mental rotation." *Cortex*, **18**, 501-514.

Kail, R. (1985). Development of mental rotation: A speed-accuracy study. *Journal of Experimental Child Psychology*, **40**, 181-192.

Kershner, J. R. (1979). Rotation of mental images and asymmetries in word recognition in disabled readers. *Canadian Journal of Psychology*, **33**, 39-50.

Kim, Y., Morrow, L., Passafiume, D., & Boller, F. (1984). Visuoperceptual and visuomotor abilities and locus of lesion. *Neuropsychologia*, **22**, 177-185.

Lohman, D. F. (1986). The effect of speed-accuracy tradeoff on sex differences in mental rotation. *Perception & Psychophysics*, **39**, 427-436.

McGuinness, D., & Bartell, T. D. (1982). Lateral asymmetry: Hard or simple-minded? *Neuropsychologia*, **20**, 629-639.

Moscovitch, M., Scullion, D., & Christie, D. (1976). Early versus late stages of processing and their relation to functional hemispheric asymmetries in face recognition. *Journal of Experimental Psychology: Human Perception & Performance*, **2**, 401-416.

Ornstein, R., Johnstone, J., Herron, J., & Swencionis, C. (1980). Differential right hemisphere engagement in visuospatial tasks. *Neuropsychologia*, **18**, 49-64.

Papanicolaou, A. C., Deutsch, G., Bourbon, W. T., Will, K. W., Loring, D. W., & Eisenberg, H. M. (1987). Convergent evoked potential and cerebral blood flow evidence of task-specific hemispheric differences. *Electroencephalography & Clinical Neurophysiology*, **66**, 515-520.

Polich, J. (1986). Hemispheric processing of multi-element displays. *Acta Psychologica*, **61**, 137-151.

Ratcliff, G. (1979). Spatial thought, mental rotation and the right cerebral hemisphere. *Neuropsychologia*, **17**, 49-54.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, **171**, 701-703.

Simion, F., Bagnara, S., Bisiacchi, P., Roncato, S., & Umiltà, C. (1980). Laterality effects, levels of processing, and stimulus properties. *Journal of Experimental Psychology: Human Perception & Performance*, **6**, 184-195.

Tapley, S. M., & Bryden, M. P. (1977). An investigation of sex differences in spatial ability: Mental rotation of three-dimensional objects. *Canadian Journal of Psychology*, **31**, 122-130.

(Manuscript received June 8, 1988.)