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MENTAL ROTATION OF TWO- AND THREE-DIMENSIONAL STIMULI BY RIGHT- AND LEFT-HANDERS

by

Essie P. Knuckle and S. M. Luria

Naval Medical Research and Development Command
Research Work Unit M0100.001-1022

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C. A. Harvey, CAPT, MC, USN
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19 November 1986

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Essie P. Knuckle
Howard University

and

S.M. Luria
Naval Submarine Medical Research Laboratory

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SUMMARY PAGE

THE PROBLEM

To compare performance by right- and left-handers on tests of mental rotation of two- and three-dimensional stimuli.

FINDINGS

There was no correlation between the two- and three-dimensional visual spatial mental rotation performance (r = .012). Performance on the two-dimensional submarine-target task was not related to initial orientation of the submarine, initial relationship between submarine and target, or to degree of rotation of the submarine. Performance was related to change in submarine-target relationship. Left-handers were better than right-handers on the two-dimensional task, but there was no difference on the three-dimensional task.

APPLICATION

These results may be applicable to the current attempts to develop selection tests for sonar school candidates.

ADMINISTRATIVE INFORMATION

Investigation was conducted under Work Unit # M0100.001-1022, Enhanced Performance with Visual Sonar Displays. It was submitted for review on 22 August 1986 and approved for publication on 19 November 1986. It will be NSMRL Report No. 1085.

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ABSTRACT

The ability of right- and left-handed men to identify two- and three-dimensional visual stimuli that have been rotated was measured. There was no correlaton between the scores on tests with two- and three-dimensional stimuli. How accurately a two-dimensional submarine-target diagram could be identified after it had been rotated was not related to the initial orientation of the submarine, the initial relationship between the submarine and a target, or the degree to which the submarine was subsequently rotated; it was, however, related to the degree to which the submarine-target relationship had been changed. Left-handers performed better than right-handers on the two-dimensional task, but there was no difference on the three-dimensional task.

The ability to reorient environmental stimuli in one's mind or to recognize spatial patterns that have been rotated may be an important ability for sonar operators and men on fire-control parties.

Many studies have investigated the time subjects take to rotate geometric and alphanumeric stimuli mentally (Shepard and Cooper, 1982). It has generally been found that reaction time increases linearly as the degree of angular rotation of the stimulus is increased (Cooper, 1975; Cooper & Shepard, 1973; Hollard & Delius, 1982; Shepard & Metzler, 1971). Further, left-right manipulations appear to be more difficult than up-down ones (Farrell, 1979), and information about "right" seems to be easier to process than information about "left" (Olson and Laxar, 1972; 1973a).

It has also been found (Braine et al, 1981) that the time required to identify the orientation of objects is influenced by the presence of other objects, which would generally be the case, of course, in the real world. There is also evidence that right-handers process information differently from left-handers (Luria et al, 1973; Olson and Laxar, 1973b). But, as Hardyck and Petrinovich (1977) pointed out, it is not clear what the relationship of handedness is to performance. Approximately equal numbers of studies have found correlations or no correlation between non-verbal performance and handedness. Yet it seems to be the case that left-handers are disproportionately represented among artists and architects (Peterson and Lansky, 1980), presumably because of the spatial abilities demanded by those tasks.

Sanders et al (1982) have argued that the confusion arises from the differences in the performance tests that have been correlated with handedness. The studies that have used the nonverbal subtests of intelligence scales have found little correlation. But those that have used tests that more clearly test spatial abilities have found a correlation.
However, most of the studies cited by Sanders et al find that left-handed men perform worse on spatial tasks than right-handers. In their own study, Sanders et al found the opposite but offered no explanation. The matter is thus still unclear.

For the past 15 years, the most widely used test of mental rotation is one which presents drawings of three-dimensional figures (Shepard and Metzler, 1971). In the real world, the ability to keep track of two-dimensional space is of more importance than three-dimensional space. Although up-down information is evidently processed much more easily that right-left information (Farrell, 1979; Maki et al, 1979; Braine et al, 1981), it is the latter that is of more important in most situations, as Shepard and Hurwitz (1985) have pointed out. Individuals have always had immediate knowledge of vertical directions, because it is defined for us by gravity. However, it is horizontal directions that are vital in finding our way around.

But what is the relationship between the ability to rotate objects mentally and the ability to orient oneself spatially? Does one predict the other? Lohmann (1979) and McGee (1979) have concluded that there are at least two distinct spatial factors, perhaps three. There are great differences in the ability of individuals to keep track of spatial relations, but the correlation between performance on two- and three dimensional rotation tasks is not clear. If these two kinds of stimuli are coded using different coordinate systems, then, as Just and Carpenter (1985) have pointed out, different processes may be involved, which would presumably produce different responses. Yet it is interesting to note that Richards and Lieberman (1985) found, unexpectedly, that the mechanisms for stereopsis and for constructing depth from two-dimensional motion are not independent; two- and three-dimensional rotation may also be related.

Sanders et al (1982) correlated the ability of their subjects to mentally rotate both two- and three-dimensional stimuli with handedness. Since they did not remark about any differences in results between these two tests, one assumes that the results were quite similar with both tests. But this is also not certain. We therefore looked into this question again.

The purpose of this study was first, to compare performance on tests of two- and three-dimensional mental rotation. A second purpose was to assess performance on a task which bore some resemblance to those which sonar and fire-control parties on submarines carry out. The third was to compare the performance of right and left-handed men.

METHOD

Tests

Two tests of mental rotation were used. The first was the three-dimensional spatial visualization test (Vandenberg, 1971) adapted from Shepard's and Metzler's (1971) study. The subjects were given 10 minutes to complete the 40 questions.

The second test was a two-dimensional test in which diagrams of a submarine and a target were presented (Figure 1). The submarine was oriented either to 0, +60, +120, -60, or -120 deg. The target was a circle presented at a constant distance from the submarine and at angles of either +30, +60, -30, or -60 deg with respect to the direction of travel of the submarine; it of course had no orientation. Each submarine orientation was presented with each target relationship four times, in random order, for a total of 80 presentations. Each presentation consisted of a standard diagram which showed the submarine at one orientation with one of the target relationships. This was followed by four other diagrams in which the submarine was at a different orientation while the target could have either the same or a different relationship to the submarine. The subject's task was to report which of these four diagrams showed the same relationship of the target and submarine as the standard diagram. Only one of the four alternatives was correct in all but three of the 80 sets. Each diagram was presented for four seconds.

The simplified Edinburgh Handedness Inventory (Oldfield, 1971; Bryden, 1977) was used to measure handedness. The subjects were also asked to state whether they were right- or left-handed. These reports were obtained in order to compare them with the results of the handedness questionnaire.

Procedure

The subjects were first informed of the nature and purpose of the study and invited to leave if they did not wish to participate. They were tested in an auditorium. They first completed the handedness questionnaire followed by the Vandenberg three-dimensional mental rotation test. Finally, they took the two-dimensional rotation test. The entire session took about 90 minutes.

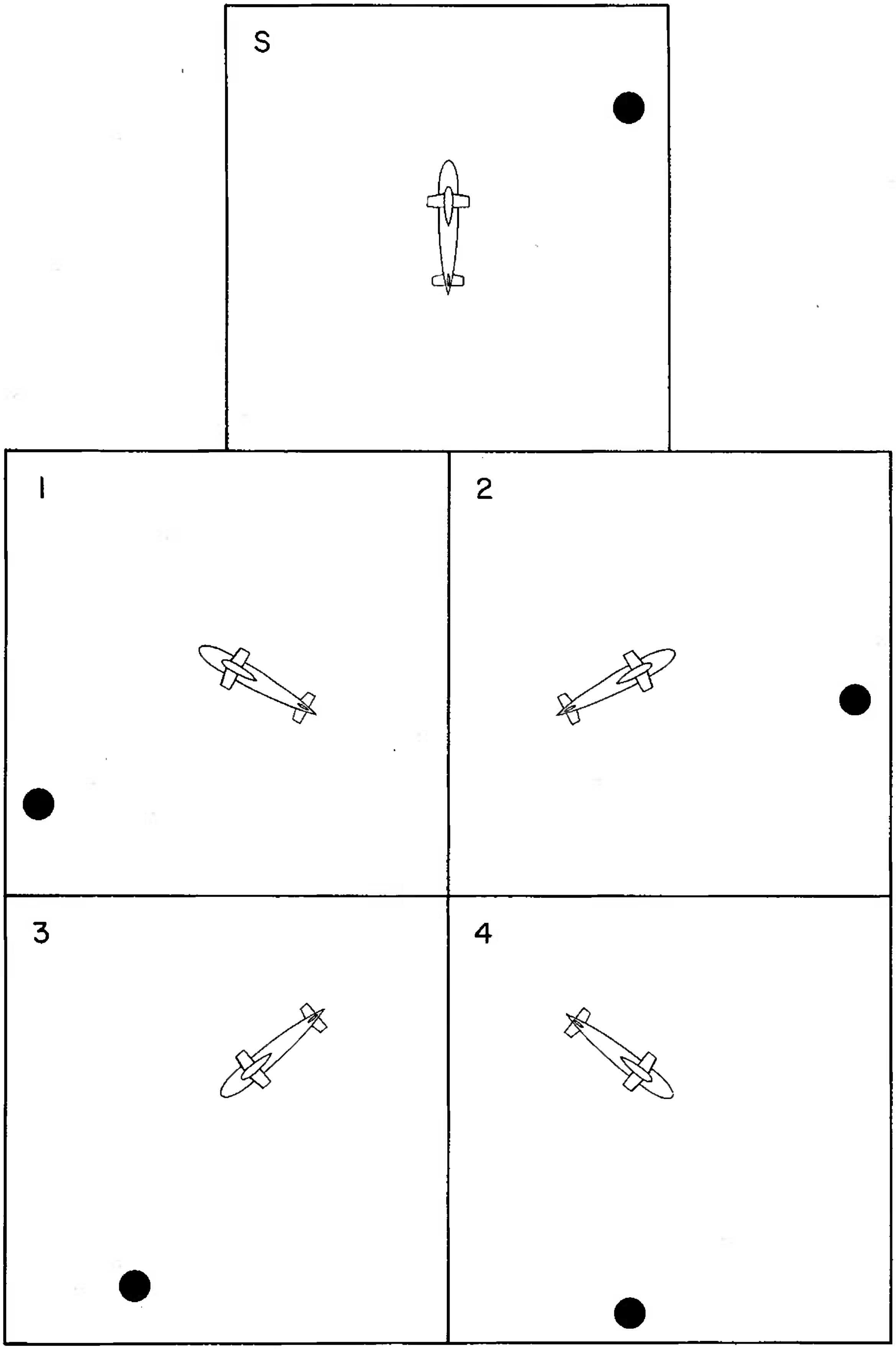

Figure 1. One set of stimuli in the test of two-dimensional rotation. S is the standard diagram; 1 to 4 are the succeeding diagrams from which the subject chooses those which, although rotated, are identical to the standard. The correct answer is 4.

Subjects

One hundred enlisted students at the Submarine School volunteered to participate. Eighty-nine were classified as right-handers and 11 as left-handers.

RESULTS

The score on the three-dimensional test was the number of correct identifications, adjusted for guessing. The score on the two-dimensional test was the number of incorrect identifications, including the omissions of the correct answers.

The scores on the two tests of mental rotation were not correlated. The Pearson r was a non-significant .012.

The scores on the three-dimensional test were not significantly different for the right- and left-handers (27.2, S.D.= 7.5; 27.7, S.D. = 13.1).

The remainder of the analysis focused on the two-dimensional test. Figure 2 shows the mean number of total errors made by all the subjects on each set of diagrams with a given initial submarine orientation. (There were 16 sets of diagrams in which the initial submarine orientation was 0 deg, and so on.) There were no differences in the mean number of errors as a function of the initial orientation of the submarine ($F(4,60)=.057$). That is, the subjects did not find it easier to perform this task when the submarine was initially oriented in one direction rather than another, to 0 deg, say, rather than -120 deg.

Figure 3 shows that there were no differences in the mean number of errors per subject as a function of the initial relationship between the submarine and the target ($F(3,60)=1.42$). Performance was not better when the target was at, say, +30 deg rather than at -60 deg.

Nor was there a difference in performance as a function of the change in orientation of the submarine. That is, when the standard diagram showed the submarine initially oriented to, say, 0 deg, it made no difference whether the submarine orientation changed, for example, by only +60 deg rather than by -120 deg (Figure 4).

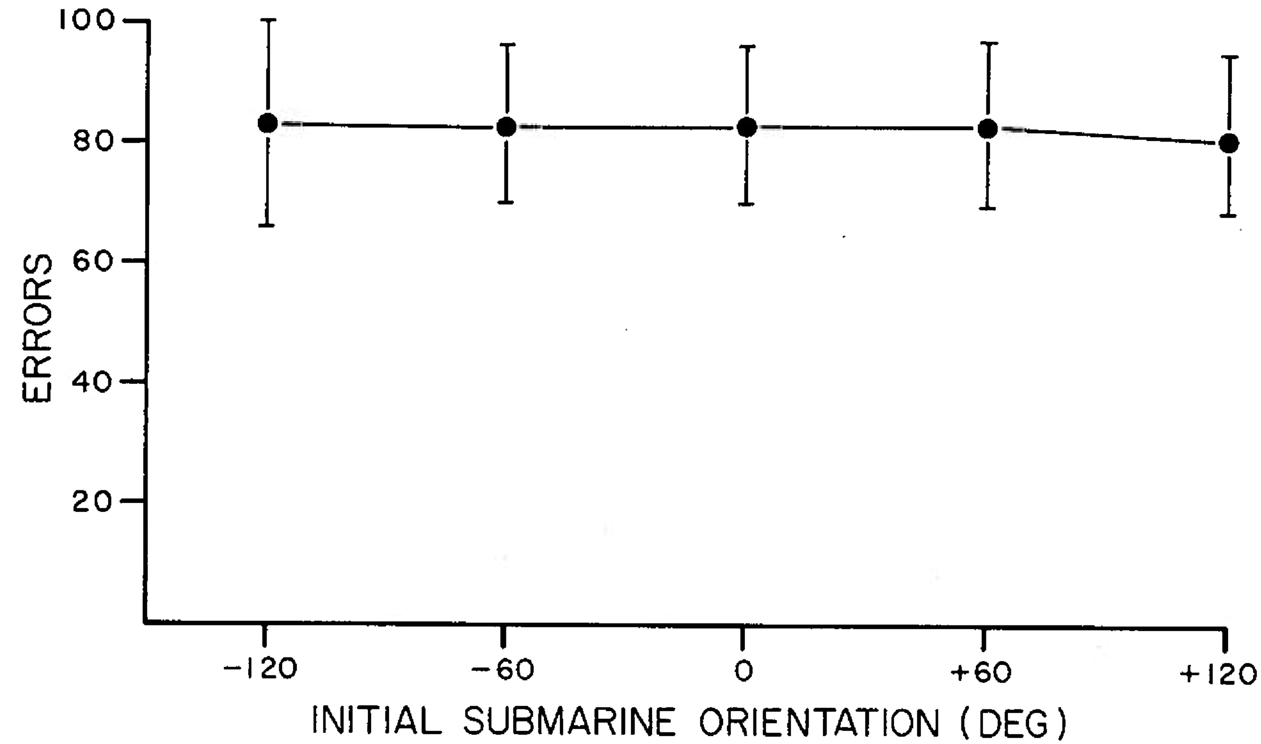

Figure 2. Mean errors on the two-dimensional test as a function of the initial orientation of the submarine. The vertical lines are the standard deviations.

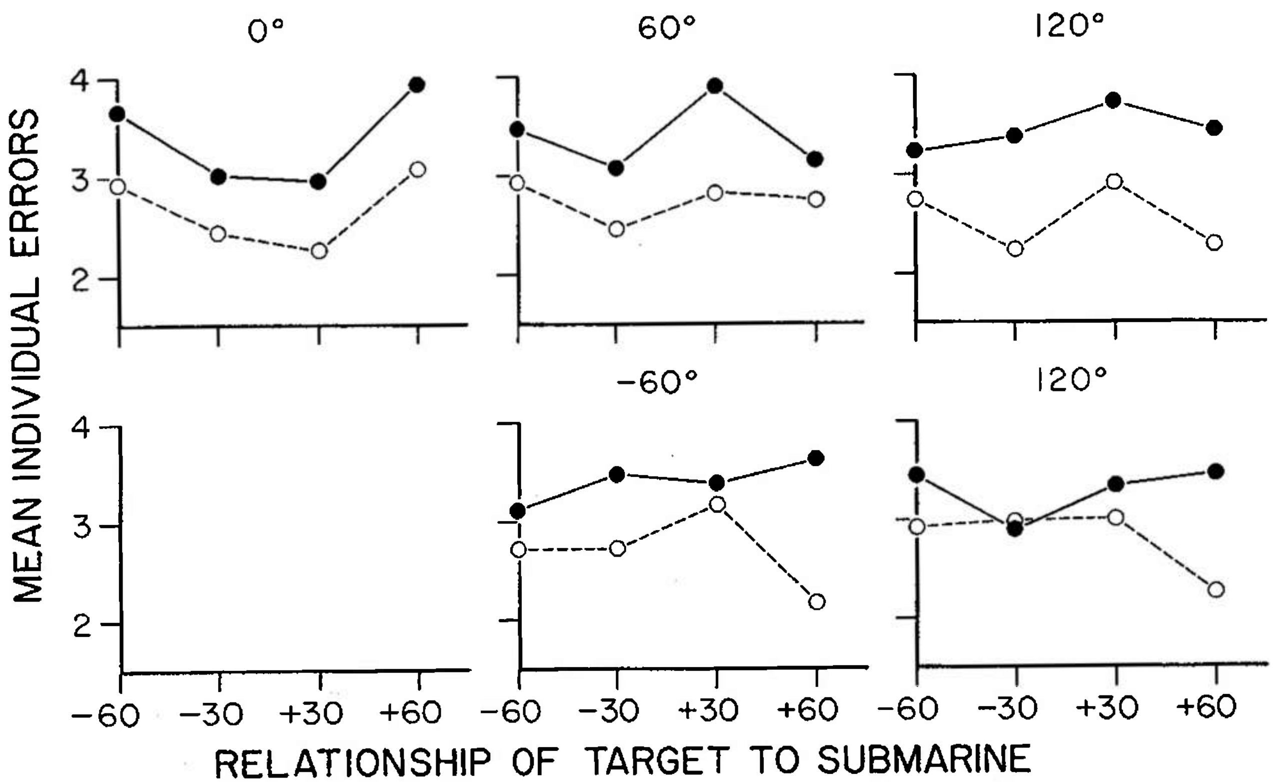

Figure 3. Mean errors on the two-dimensional test as a function of the initial angle of the target with respect to the direction of travel of the submarine. The five panels give the results for each initial submarine orientation. The solid lines are the results for the right-handed subjects, the dashed lines for the left-handed subjects.

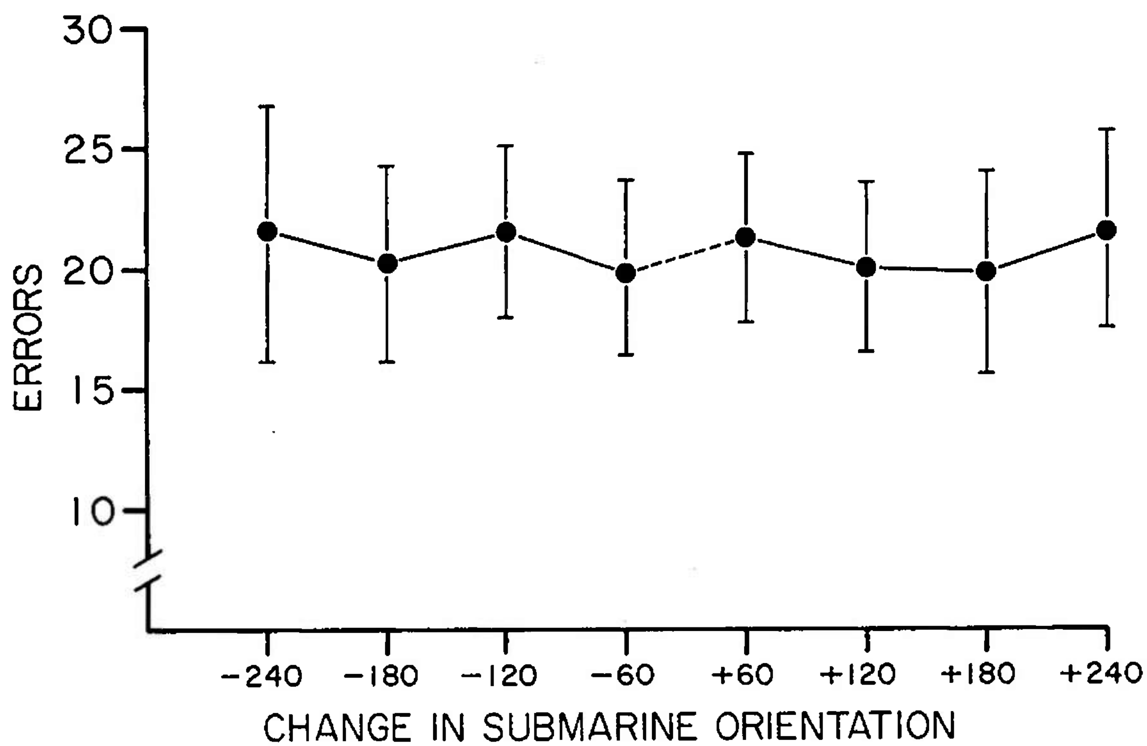

Figure 4. Mean errors on the two-dimensional test as a function of the degree of rotation of the submarine. The vertical lines are the standard deviations.

Only one variable had a significant effect on performance. That was the change in the target relationship (Figure 5). The number of errors was significantly reduced when the the relationship of the target to the submarine was changed by 90 deg compared to a change of 30 or 60 deg ($F(7,235) = 35.54$, $p < .01$).

It is also clear from these figures that there were no differences in performance as a result of changing either the submarine orientation or the position of the target to the right or left.

The effects of handedness of performance was examined. The results of the handedness questionnaire correlated significantly with the self-identified handedness of the subjects ($r = .72$, $p < .001$). Separate analyses of variance were computed for the right- and left-handed groups. The conclusions were the same for both groups for all these conditions. However, the number of errors made by the left-handers was significantly less than that made by the right-handers for every one of the 20 conditions of submarine and target orientation except one (correlated $t(df=19) = 7.95$, $p<.01$). Figure 3 shows clearly that the mean number of errors made by the left-handers was less than that made by the right-handers in every condition except for a slight inversion in one. For example, when the initial diagram showed the submarine oriented to 0 deg with the target at -60 deg, the left-handers made an average of 2.86 errors; the right-handers made an average of 3.47 errors in that condition, and so on. There were, however, no differences in the performance of the right-and left-handers on the test of three-dimensional rotation.

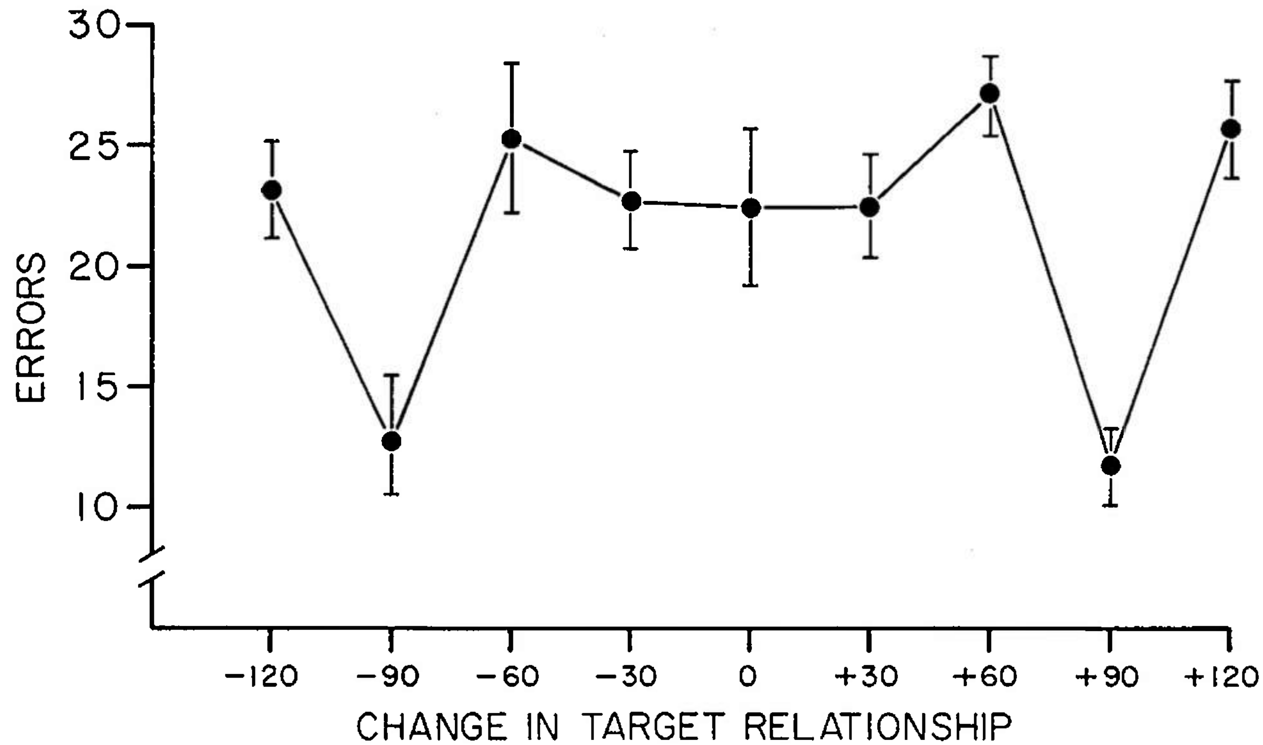

Figure 5. Mean errors on the two-dimensional test as a function of the change in the angle of the target with respect to the direction of travel of the submarine. The vertical lines are the standard deviations.

DISCUSSION

The scores on these two tests of mental rotation showed a wide range, but they did not correlate and are apparently tapping different abilities.

The left-handers scored significantly better than right-handers on the two-dimensional test. As noted above, several investigators have found that left-handers are worse than right-handers on performance tasks, as opposed to verbal tasks. The present results, rather, confirm those of Sanders et al (1982) who found that left-handed men had higher spatial scores than right-handed men. However, we did not find this to be true for the three dimensional test, a finding which conforms to the reports of McGee (1976) and Yen (1975) who also found no differences on this test between left- and right-handers.

It seems likely that the two-dimensional test of mental rotation is much more amenable to verbal coding, and would therefore appear to belong to the group of studies which Sanders et al criticize as not tapping spatial ability and which found no relation to handedness. It is not clear why this difference occurred in the present study.

In the two-dimensional test, performance did not depend on the initial orientation of the submarine or the initial relation between it and the target. Nor did the ability of the subjects to identify the diagram with the correct relationship improve when the submarine was rotated less. The only variable which affected performance significantly was the angular change in the relation between target and submarine. Here, not surprisingly, performance was best when the relationship changed by 90 deg compared to changes of only 30 or 60 deg. The explanation undoubtedly is that the 90 deg shift was perceptually obvious, whereas the other shifts were more difficult to see and may all have been coded verbally with about equal difficulty.

Nor was performance differentially affected by shifts to the right or left, although such differences have been reported (Olson and Laxar, 1973). Previous investigations, however, have studied speed of response. We have rather been concerned with accuracy, which in many situations, is probably of more importance than speed of response, particularly aboard ship. But Egan (1978) has pointed out that different mental processes are reflected in accuracy and latency scores. This may explain the discrepancy.

The wide range of scores on both tests suggests that it would be useful to correlate them with proficiency ratings of men in jobs which appear to utilize these abilities. The lack of correlation between the two mental rotation tests indicates that they cannot be used interchangeably.

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target relationship had been changed. Left-handers performed better than right-handers on the two-dimensional task, but there was no difference on the three-dimensional task.