Perceptual and Motor Skills, 1978, 47, 599-604.

MENTAL ROTATIONS, A GROUP TEST OF THREE-DIMENSIONAL SPATIAL VISUALIZATION[1]

STEVEN G. VANDENBERG[2] AND ALLAN R. KUSE

Institute for Behavioral Genetics, University of Colorado

Summary.—A new paper-and-pencil test of spatial visualization was constructed from the figures used in the chronometric study of Shepard and Metzler (1971). In large samples, the new test displayed substantial internal consistency (Kuder-Richardson 20 = .88), a test-retest reliability (.83), and consistent sex differences over the entire range of ages investigated. Correlations with other measures indicated strong association with tests of spatial visualization and virtually no association with tests of verbal ability.

In 1971 Shepard and Metzler published a report of a chronometric study of mental imagery. The stimuli used were two-dimensional drawings of three-dimensional objects produced by a computer. A nearly perfect correlation was found between (a) the amount of rotation of each stimulus from the position of a comparison stimulus, and (b) the time it took individual subjects to decide whether or not the two objects were identical except for rotation. We here report the development of a paper-and-pencil test of spatial visualization, based on the stimuli used by Shepard and Metzler. This test was constructed from India ink drawings. Each original stimulus was a two-dimensional projection of one of five three-dimensional objects "drawn" by the computer and displayed on an oscilloscope. Each stimulus was shown in a different orientation because it had been rotated a specified amount about the vertical axis. The test is named Mental Rotations because that is the name given by Shepard and Metzler to the hypothesized cognitive process required.

The Mental Rotations Test contains 20 items in five sets of four items. Each item consists of a criterion figure, two correct alternatives, and two incorrect ones or "distractors." Correct alternatives are always identical to the criterion in structure but are shown in a rotated position. For half the items in the test, the distractors are rotated mirror-images of the criterion, while distractors in the other 10 items are rotated images of one or two of the other criteria. Items illustrating the two types of distractors are presented in Fig. 1. The recommended procedure for scoring is to count each line (item) as

---

[1]Some of the results reported here are made possible by collaboration of a group of investigators (G. C. Ashton, R. C. Johnson, M. P. Mi, and M. N. Rashad at the University of Hawaii, and J. C. DeFries, G. E. McClearn, S. G. Vandenberg and J. R. Wilson at the University of Colorado) supported by NSF Grant GB-34720 and Grant HD-06669 from the National Institute of Child Health and Human Development.

[2]Sample copies of the test and the answer key, as well as a more detailed explanation of the selection of the items, can be obtained from the first author at the following address: Dr. S. G. Vandenberg, Department of Psychology, University of Colorado, Boulder, Colorado 80309.

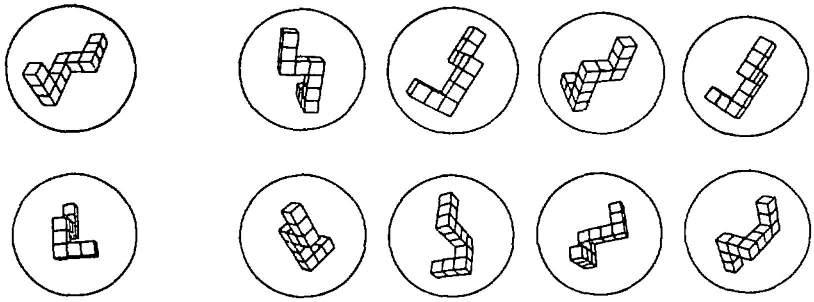

FIG. 1. Sample items from the Mental Rotations Test. The first and fourth alternatives in the first item are correct; the distractors are mirror images of the criterion figure. In the second item, the second and third alternatives are correct; the distractors are rotated images of other criterion figures.

correct if both choices are correct and to give no credit otherwise. This eliminates the need to correct for guessing.

Administration of the Mental Rotations Test to university students, high school students, and elementary school pupils has shown that it can be completed by most subjects in 10 min. The reliability of the test is satisfactory. In a sample of 3,268 adults and adolescents of age 14 yr. or older, the Kuder-Richardson 20 was .88 (Wilson, DeFries, McClearn, Vandenberg, Johnson, & Rashad, 1975); in a similar sample of 336 subjects, the test-retest correlation was .83 after an interval of one year or more and in an age corrected sample of 456 the test-retest reliability after a year or more was .70 (Kuse, 1977). The test has been used in several studies of the genetics of spatial abilities (DeFries, Vandenberg, McClearn, Kuse, Wilson, Ashton, & Johnson, 1974; Fain, 1976; Park, 1975; Spuhler, 1976; Yen, 1975). There are clear indications of a sex difference in favor of males, but no evidence for X-chromosome linkage (DeFries, Ashton, Johnson, Kuse, McClearn, Mi, Rashad, Vandenberg, & Wilson, 1976).

Product-moment correlations of the Mental Rotations Test with a number of other spatial ability tests for samples of 456 and 3,435 individuals tested in Hawaii are given in Table 1. The former sample is described in Kuse (1977). The latter consists of Americans of European Ancestry between the ages of 14 and 60 yr. living in Hawaii. Table 2 presents further correlations between a larger number of spatial ability tests (including Mental Rotations) and three tests of verbal ability in another sample of 172 individuals also tested in Hawaii. In general, the latter correlations are somewhat lower than might be expected because of restriction of range of ability due to the fact that the subjects were largely University of Hawaii undergraduate students. Over-all, Mental Rotations was most often associated with other tests of spatial visualization and, in general, showed only low correlations with tests of verbal ability. Correlations have recently been obtained by us in a study in which the

TABLE 1
PEARSON CORRELATIONS BETWEEN SPATIAL TESTS

Tests	1	2	3	4	5	6	7
1. Mental Rotations		.62	.36	.42	.44	.50	.68
2. Card Rotations	.58		.37	.50	.48	.50	.60
3. Elithorn Mazes	.32	.34		.33	.38	.31	.36
4. Paper Form Board	.41	.46	.33		.44	.49	.46
5. Hidden Patterns	.40	.44	.36	.50		.39	.42
6. Block Design							.53
7. Identical Blocks							

Note.—Above diagonal are correlations for 456 subjects and below diagonal are correlations for 3,435 subjects.

Mental Rotations Test, the Spatial Relations subtest of the Differential Abilities Test (Bennett, Seashore, & Wesman, 1947), the Chair-Window Test (Barratt, 1953), and the Identical Blocks Test (Stafford, 1962) were administered to 197 female and 115 male students in undergraduate psychology classes at the University of Colorado. Shortened time limits were used: each test was divided into two parts, with 3½ min. allowed for each part. For this study the Mental

TABLE 2
CORRELATIONS BETWEEN SPATIAL AND VERBAL TESTS ($n = 172$)

	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Mental Rotations	46	24	29	34	22	35	30	19	05	08	00	03	07
2. Object Aperture		21	33	34	33	38	03	25	−01	−04	12	07	17
3. Cube Comparisons			39	37	29	27	28	21	18	13	18	03	10
4. DAT Spatial Relations				44	34	34	27	16	12	10	06	02	03
5. Card Rotations					38	36	24	10	02	00	08	06	04
6. Flags						19	09	21	20	21	16	17	02
7. Copying							35	22	21	19	14	10	05
8. Hidden Patterns								21	35	33	17	09	16
9. Hidden Figures									27	36	33	21	15
10. Paper Form Board										60	26	10	12
11. Folded Squares											18	12	−04
12. Vocabulary												30	14
13. Word Endings													25
14. Verbal Reasoning													

Rotations Test was used counting each figure correctly marked as one and each incorrectly marked figure as minus one. Scoring of the Spatial Relations subtest was according to the usual procedure for the Differential Aptitude Test (DAT). For the Chair-Window Test and the Identical Blocks Test, the formula "right minus one-fifth wrong" was used. Split-half reliabilities corrected by the Spearman-Brown formulas were .79, .77, .69, and .78, respectively, suggesting that all four tests are comparable in this respect.

TABLE 3
MEANS AND STANDARD DEVIATIONS FOR MEN AND WOMEN ON TWO PARTS OF FOUR SPATIAL TESTS ($N = 312$)

Variable	Men ($n = 115$)		Women ($n = 197$)			
	M	*SD*	*M*	*SD*	t	p
Mental Rotations						
Part 1	9.92	4.42	7.02	4.09	5.70	.001
Part 2	9.14	4.18	6.15	3.45	6.37	.001
Spatial Relations						
Part 1	19.00	5.51	15.45	5.66	5.30	.001
Part 2	10.70	5.10	9.68	4.02	1.80	
Chair-Window						
Part 1	9.16	2.78	7.02	3.61	5.48	.001
Part 2	7.68	3.42	6.40	3.52	2.97	.01
Identical Blocks						
Part 1	6.07	3.40	3.42	2.79	6.97	.001
Part 2	5.73	3.11	4.09	2.65	4.56	.001

Means and standard deviations for the men and women are shown in Table 3, along with the results of t tests, and correlations for the total sample are shown in Table 4. It is clear from these correlations and those presented earlier that the Mental Rotations Test compares well with other tests of spatial ability, especially tests of spatial visualization. Subjects report that it is more difficult to solve the items verbally in the Mental Rotations Test than in the other spatial tests. If so, this may explain why the usual sex difference in favor of males is more pronounced. That the sex difference is large and consistent over a wide age range in the general population is clearly demonstrated in Fig. 2. These curves were obtained by Wilson, *et al.* (1975) in a sample of 2,498 individuals tested in Hawaii.

TABLE 4
CORRELATIONS BETWEEN TOTAL SCORES ON FOUR SPATIAL TESTS ($n = 312$)

Tests	2	3	4
1. Mental Rotations	.50	.45	.54
2. Spatial Relations		.37	.43
3. Chair-Window			.39
4. Identical Blocks			

Results obtained for a small sample of elementary school children (Vandenberg, 1975) suggest that the Mental Rotations Test may be useful in studies of the development of spatial ability. Such an investigation would be particularly interesting in view of the idea that the sex difference in spatial ability increases with the onset of puberty, either because of the effect of hormones or due to greater pressure of sex-role expectations.

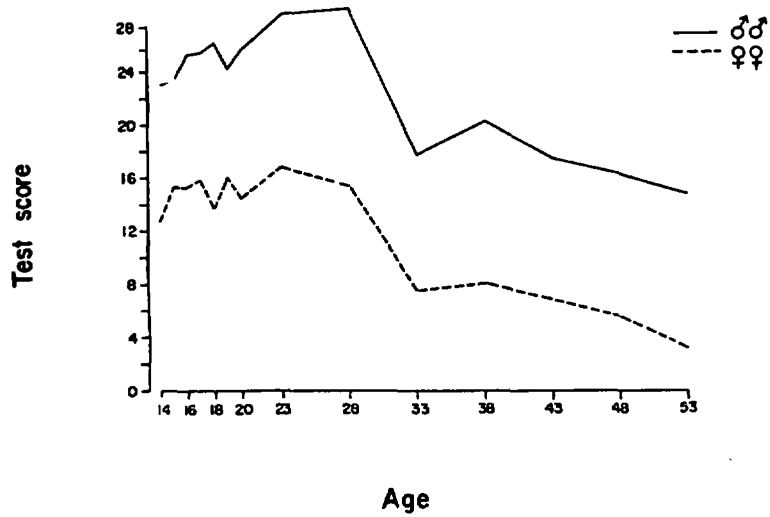

FIG. 2. Male and female age curves for the Mental Rotations Test (after Wilson, *et al.*, 1975)

REFERENCES

BARRATT, E. S. An analysis of verbal reports of solving spatial problems as an aid in defining spatial factors. *Journal of Psychology*, 1953, 36, 17-25.

BENNETT, G. K., SEASHORE, H. G., & WESMAN, A. G. *Differential Aptitude Tests.* New York: Psychological Corp., 1947.

DEFRIES, J. C., ASHTON, G. C., JOHNSON, R. C., KUSE, A. R., MCCLEARN, G. E., MI, M. P., RASHAD, M. N., VANDENBERG, S. G., & WILSON, J. R. Parent-offspring resemblance for specific cognitive abilities in two ethnic groups. *Nature*, 1976, 261, 131-133.

DEFRIES, J. C., VANDENBERG, S. G., MCCLEARN, G. E., KUSE, A. R., WILSON, J. R., ASHTON, G. C., & JOHNSON, R. C. Near identity of cognitive structure in two ethnic groups. *Science*, 1974, 183, 338-339.

FAIN, P. R. Major gene analysis: an alternative approach to the study of the genetics of human behavior. Unpublished doctoral dissertation, Univer. of Colorado, 1976.

KUSE, A. R. Familial resemblances for cognitive abilities estimated from two test batteries in Hawaii. Unpublished doctoral dissertation, Univer. of Colorado, 1977.

PARK, J-Y. A study of multivariate cognition in Korea in relation to environmental and hereditary influences. Unpublished doctoral dissertation, Univer. of Hawaii, 1975.

SHEPARD, R. N., & METZLER, J. Mental rotation of three-dimensional objects. *Science*, 1971, 171, 701-703.

SPUHLER, K. P. Family resemblance for cognitive performance: an assessment of genetic and environmental contributions to variation. Unpublished doctoral dissertation, Univer. of Colorado, 1976.

STAFFORD, R. E. *Identical Blocks, Form AA.* University Park: Pennsylvania State Univer., Office of Student Affairs, 1962.

VANDENBERG, S. G. Sources of variance in performance on spatial tests. In J. Eliot & N. J. Salkind (Eds.), *Children's spatial development.* Springfield, Ill.: Thomas, 1975. Pp. 57-66.

WILSON, J. R., DEFRIES, J. C., MCCLEARN, G. E., VANDERBERG, S. G., JOHNSON, R. C., & RASHAD, M. N. Cognitive abilities: use of family data as a control to assess sex and age differences in two ethnic groups. *International Journal of Aging and Human Development*, 1975, 6, 261-276.

YEN, W. M. Sex-linked major-gene influences on selected types of spatial performance. *Behavior Genetics*, 1975, 5, 281-298.

Accepted August 13, 1978.