Behavior Genetics, Vol. 13, No. 4, 1983

Spatial Ability and Throwing Accuracy

Rosemary Jardine[1] and N. G. Martin[1]

Received 20 Oct. 1982—Final 28 Feb. 1983

Significant correlations have been found between several tests of throwing accuracy and spatial ability. This replicates an earlier finding and supports the hypothesis that past selection acting on hunting skills in males may partly account for the superior spatial ability observed in males today.

KEY WORDS: spatial ability; throwing accuracy; sex differences; human evolution.

INTRODUCTION

In an attempt to explain the superior spatial skill of males, several studies have investigated the hypothesis that spatial ability is enhanced by an X-linked recessive gene.

Some of the evidence based on intrafamilial correlations supports the X-linkage hypothesis of superior male spatial ability (Stafford, 1961; Hartlage, 1970; Bock and Kolakowski, 1973; Yen, 1975) while more recent work, including our own, does not (DeFries *et al.*, 1976a, 1979; Bouchard and McGee, 1977; Loehlin *et al.*, 1978; Park *et al.*, 1978; Jardine and Martin, 1983).

While the X-linkage hypothesis now seems unlikely, the evidence that experiential factors are critical in the development of spatial skills is not convincing. If sex differences in spatial skill reflect differential learning due to sex-typed activities, then appropriate training should result in improved performance. Brinkmann (1966), studying male and female high-school students, found after 3 weeks of instruction that the girls did not significantly differ from the boys in their performance on the Spatial

[1] Department of Population Biology, Research School of Biological Sciences, Australian National University, Canberra, Australia.

0001-8244/83/0700-0331$03.00/0

Relations Subtest of the Differential Aptitude Test. Other workers have not been able to demonstrate the positive effects of training (Faubian *et al.*, 1942; Smith, 1948; Thomas *et al.*, 1973; McGee, 1978) or have shown that increases in performance following training do not generalize to a related test (Connor *et al.*, 1978). Furthermore, McGee (1979) has argued that even if an increase in performance is obtained after training on spatial tasks, this does not explain the sex difference. Assuming that the female deficit in spatial ability results from differential learning experience, then females should respond more favorably than males to training. McGee (1979) has found no evidence for a differential response to training on spatial tasks.

The ubiquity of sex differences in spatial tasks also argues against the importance of experiential factors. Male superiority on spatial tasks has been demonstrated in America, Europe, India, South Africa, and Australia (see Porteus, 1965, Chap. 6). While this may reflect similarities in the experiences of males and females across cultures, it may also reflect an evolutionary basis for sex differences in spatial ability.

Inspired by the sex-linkage hypothesis, Kolakowski and Malina (1974) argued that throwing accuracy in males would have been necessary for successful hunting, that spatial ability is involved in throwing accuracy, and that the superior male spatial skill evidenced today is a remnant of this past selection. As evidence for this argument they found a significant positive relationship between spatial ability (as measured by the PMA spatial test) and vertical accuracy in a ball-throwing task.

In fact, Kolakowski and Malina's argument and the interpretation of their findings are quite independent of the sex-linkage hypothesis and are equally compatible with sex-limited gene expression or other forms of transmission. Nevertheless, their results suggest a possible evolutionary origin for sex differences in spatial ability. We have attempted to replicate Kolakowski and Malina's (1974) finding by investigating the relationship between spatial ability and throwing accuracy in a sample of twins and their parents.

METHOD

Subjects

A sample of 83 pairs of twins (20 MZ males, 12 MZ females, 14 DZ males, 17 DZ females, 20 DZ opposite sex) and their parents was obtained from the Australian NH and MRC Twin Registry. The twins were aged between 13 and 19 years.

Data were collected for Kolakowski and Malina's (1974) test of throwing accuracy, several spatial visualization tasks, IQ (Raven's Progressive Matrices), and personality measures (16PF). Only the results for spatial ability and throwing accuracy are reported here.

Tests were administered in the following order.

1. Tests of Throwing Accuracy. Two tests of throwing accuracy were employed. The first was identical to Kolakowski and Malina's (1974) vertical ball-throwing task. The second, a horizontal ball-throwing task was an adaptation of Kolakowski and Malina's task considered to be more suitable for females.

The Vertical Ball-Throwing Task required subjects to throw tennis balls at a vertical target, 2.7 × 2.7 m, on which were inscribed five concentric circles from 0.3 to 1.5 m in diameter. The center of the "bull's eye" was 1.35 m from the floor. The target was divided into a grid of 81 0.3-m squares to enable scoring.

Three measures were derived from each throw: (1) vertical deviation—the absolute distance from the central row in either direction, scored 0 to 4; (2) horizontal deviation—the absolute distance from the central horizontal row, scored 0 to 4; and (3) radial distance—calculated as the square root of the sum of squares of the horizontal and vertical deviations (i.e., the straight-line distance from the center of the target to the grid section where the ball hit).

The subjects (at a distance of 9.0 m from the target) were allowed 20 overarm practice throws at the target, after which they executed another 20 overarm throws that were recorded. The score recorded for each throw was the number of the square where the ball hit. If the ball missed the target, both vertical and horizontal deviations were scored 5. The three measures of accuracy were derived from the mean of 20 throws.

The Horizontal Ball-Throwing Task was a slightly modified version of the above. The target was lying on the floor but had the same dimensions as, and markings similar to, the vertical ball-throwing target (except that the concentric circles were omitted).

Subjects stood 9.0 m from the center of the target and threw 20 underarm practice throws followed by 20 test throws that were recorded. The three measures of accuracy derived for the vertical ball-throwing task were also calculated for each test throw in the horizontal ball-throwing task.

The horizontal and vertical direction variables used by Kolakowski and Malina (1974), in which deviations are given values of 0.5 to 9.5, are clearly not accuracy scores because, when averaged over 20 throws, they merely measure the bias in the scatter of throws. For this reason, we have not included them in our study.

The horizontal aiming task was considered more suitable than the vertical task for females since it required underarm rather than overarm throwing. When throwing ability has been studied it has been consistently found that males are superior to females, even in children as young as 3.5 years (Gesell *et al.*, 1940). The superior ability of males reflects their more efficient throwing style and greater coordination in making overarm movements (Gesell *et al.*, 1940). Underarm throwing in the horizontal ball-throwing task eliminates a movement females find awkward. Thus the task may give a more accurate reflection of the aiming skill of females than the vertical task.

2. *Money's Road Map Test of Direction Sense (Money* et al., *1965).* This test consists of a schematic outline map of several city streets with a standard route marked through the streets. The subject must imagine following the route and decide whether each turn on the route would be to the left or the right. This untimed test was modified because pilot work showed that, in its original form, it provided little discrimination between subjects. It was therefore administered with a 1-min time limit, which a second pilot trial suggested would provide a more adequate distribution of scores.

3. *Paper Folding Test (French* et al., *1963).* This test involves mental spatial transformations in three dimensions. It consists of 20 items which illustrate two or three folds being made in a square sheet of paper. A drawing of the folded paper shows where a hole is punched in it. The subject selects one of five drawings to show how the sheet would appear when fully opened.

4. *Cube Comparisons Test (French* et al., *1963).* This is a test of three-dimensional spatial orientation. It consists of 42 items, each presenting two drawings of a cube. Assuming that no cube can have two faces alike, the subject is asked to indicate which items present drawings that can be of the same cube and which present drawings of cubes that must be different.

Scores for the number of correct responses on each of the spatial tests were obtained.

RESULTS

Table I shows the means and standard deviations for the throwing accuracy and spatial ability variables broken down by sex and generation. To assess whether there were any overall significant differences in the means of the four groups, one-way analyses of variance were performed. The between-groups term was significant for all variables and orthogonal contrasts of the means for the effects of sex, generation, and the sex × generation interaction are shown in Table II. For all the throwing accuracy measures, males performed significantly better than females and twins

Table I. Means and Standard Deviations for All Variables

Variables	Fathers ($N = 83$)		Mothers ($N = 83$)		Male twins ($N = 88$)		Female twins ($N = 78$)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Vertical ball throwing								
Vertical Deviation (V-VDE)	0.97	0.45	1.92	1.02	0.88	0.29	1.40	0.65
Horizontal Deviation (V-HDE)	0.76	0.38	1.65	0.94	0.69	0.34	1.25	0.70
Radial Distance (V-RAD)	1.40	0.56	2.73	1.34	1.30	0.40	2.07	0.92
Horizontal ball throwing								
Vertical Deviation (H-VDE)	1.69	0.67	2.64	0.96	1.73	0.66	2.14	0.79
Horizontal Deviation (H-HDE)	0.94	0.65	1.78	1.10	0.92	0.54	1.27	0.79
Radial Distance (H-RAD)	2.13	0.90	3.40	1.36	2.16	0.81	2.70	1.08
Money's Road Map Test (RMT)	19.21	7.49	11.33	6.84	16.23	8.54	9.78	5.63
Paper Folding Test (PF)	9.51	4.33	7.99	4.13	11.55	4.09	9.99	3.61
Cubes Comparisons Test (CC)	20.90	6.78	15.95	5.22	23.50	7.80	20.06	6.68

Table II. Orthogonal Contrasts of the Means for the Effects of Sex, Generation, and the Sex × Generation Interaction (Variable Abbreviations Are Those Introduced in Table I)

Variable	Sex[a]	Generation[b]	Sex × generation[c]
V-VDE	1.47***	0.61***	0.43**
V-HDE	1.45***	0.47**	0.33**
V-RAD	2.10***	0.76***	0.55**
H-VDE	1.36***	0.46**	0.53**
H-HDE	1.20***	0.53**	0.49**
H-RAD	1.80***	0.67**	0.73**
RMT	−14.32***	4.52**	−1.43
PF	−3.08**	−4.04***	0.04
CC	−8.18***	−6.50***	−1.72

[a] Values are means of females minus males.
[b] Values are the parental mean minus the twin mean.
[c] Values are the mother plus male twin mean minus the father plus female twin mean.
* $.01 < P < .05$.
** $.001 < P < .01$.
*** $P < .001$.

significantly better than their parents, the sex × generation interactions indicating that the sex effects were significantly more pronounced between fathers and mothers than between male and female twins. Because the accuracy variables are all positively skewed, the analysis of variance and contrasts were repeated with square root and logarithmic transformations of the raw measures but this made no difference to the significance of the results.

The three spatial visualization tests all showed significant differences in sex and generation means. For both the Cube Comparisons and the Paper Folding Tests males performed better than females, and twins better than parents. For Money's Road Map Test of Direction Sense the performance of males was again superior to that of females but the generation effect was reversed, parents scoring better than twins. Thus, while the superior performance of males was consistently observed in the various tests of spatial skill (cf. Hyde, 1981; Maccoby and Jacklin, 1974), generation differences were also important, with female twins sometimes performing at least equal to, or better than, fathers, as, for example, in the Paper Folding Test.

Because of these differences in sex and generation means, we examined the relationship between spatial ability and throwing accuracy separately for mothers, fathers, and male and female twins. Significant correlations were found between age and several of the spatial and throwing accuracy tests, so we calculated age-corrected partial correlations between these measurements (Table III). Because we have made a clear prediction that spatial ability will enhance throwing accuracy, we expect to find negative correlations (low values for the throwing variables representing greater accuracy) and thus may employ one-tail tests of significance.

Of 72 correlations, 53 are less than zero, of which 25 are significant at the 10% level, 13 at the 5% level, and 1 at the 1% level, considerably more than expected by chance alone. Recalculation of the partial correlation coefficients with square root or logarithmic transformations of the accuracy variables resulted in only trivial alteration of the values tabled.

DISCUSSION

Our finding that males score better on both throwing accuracy and spatial tests supports earlier results (Gesell *et al.*, 1940; Stafford, 1961). We have also found generation differences to be important, with female twins sometimes equaling the fathers' performance. It is not clear, however, whether the generally superior spatial ability and throwing accuracy of the adolescent twins are due to the decline in these abilities and skills in adults or to the greater familiarity of test taking and ball throwing that would be expected in school-age twins (cf. Walker *et al.*, 1981).

It has been suggested that these sex differences in spatial ability reflect the evolutionary adaptations that would have been necessary in the historical role of males as hunters (Masica *et al.*, 1969). Kolakowski and Malina (1974) tested a corollary of this hypothesis by attempting to relate spatial skills to throwing accuracy, a skill that would presumably have been important in hunting. In most respects we have replicated their finding of a significant relationship between spatial ability and throwing accuracy, although our correlations are lower than the value of 0.37 which they reported from a sample of 67 boys aged 14 to 16 years, similar to our male twin sample. Despite the fact that we have found significant correlations between spatial ability and throwing accuracy, they are too small for it to be practical to explore the genetic and environment causes of this covariation (Martin and Eaves, 1977), particularly since our family data are compatible with only low degrees of genetic variation for these traits (Jardine and Martin, 1983).

In contrast to the results of these authors, however, we find correlations to be equally large with both the horizontal and the vertical components of accuracy. The fact that correlations in twins are strongest with

Table III. Partial Correlations (Age Corrected) Between Measures of Spatial Ability and Throwing Accuracy

Variable	Fathers			Mothers			Male twins			Female twins		
	RMT	PF	CC	RMT	PF	CC	RMT	PF	CC	RMT	PF	CC
V-VDE	−0.18*	0.06	−0.10	−0.20**	0.14	−0.12	−0.14*	0.07	−0.02	0.01	−0.18*	0.13
V-HDE	−0.15*	0.00	−0.09	−0.20**	0.13	−0.18*	−0.04	0.01	−0.04	−0.00	−0.10	0.12
V-RAD	−0.18*	0.04	−0.10	−0.21**	0.13	−0.16*	−0.12	0.05	−0.03	0.01	−0.15*	0.13
H-VDE	−0.18*	−0.20**	−0.13	−0.16*	−0.02	−0.02	−0.20**	−0.11	−0.03	−0.22**	−0.22**	−0.03
H-HDE	0.04	−0.03	0.01	−0.15*	0.03	0.00	−0.24**	−0.11	−0.10	−0.24**	−0.29***	−0.09
H-RAD	−0.09	−0.14	−0.06	−0.17*	0.00	−0.00	−0.23**	−0.12	−0.06	−0.23**	−0.25**	−0.06

* $0.05 < P < 0.10$, one-tail test.
** $0.01 < P < 0.05$, one-tail test.
*** $0.001 < P < 0.01$, one-tail test.

the underarm throwing task may indicate that this is a more valid test of accuracy than the vertical throwing task which involves the learned skill of throwing overarm, this being particularly difficult for females. Of the correlations significant at the 5% level, nine are with the test of direction sense (RMT), four with the Paper Folding Test (PF), and none with the Cubes Comparison Test (CC). Although none of the tests of spatial ability we used was the same as that used by Kolakowski and Malina (1974), they represent the major components of spatial ability as identified by Michael *et al.* (1957) and presumably sample skills similar to those measured by the PMA spatial test.

Kolakowski and Malina (1974) also speculated that spatial ability may have been selected for in direction finding, a further important skill for nomadic hunters. While we included no practical task to measure this skill in the present study, correlations of 0.30 to 0.39 between the test of direction sense (RMT) and the other two spatial tests (PF and CC) support the notion that this may also be a fruitful area in which to explore an evolutionary origin of superior male spatial ability.

REFERENCES

Bock, R. D., and Kolakowski, D. (1973). Further evidence of sex-linked major-gene influence on human spatial visualizing ability. *Am. J. Hum. genet.* **25**:1–14.

Bouchard, T. J., and McGee, M. G. (1977). Sex differences in human spatial ability: Not an X-linked recessive gene effect. *Soc. Biol.* **24**:332–335.

Brinkmann, E. H. (1966). Programmed instruction as a technique for improving spatial visualisation. *J. Appl. Psychol.* **50**:179–184.

Connor, J. M., Schackman, M., and Serbin, L. A. (1978). Sex-related differences in response to practice on a visual-spatial test and generalisation to a related test. *Child Dev.* **49**:24–29.

DeFries, J. C., Ashton, G. C., Johnson, R. C., Kuse, A. R., McClearn, G. E., Mi, M. P., Rashad, M. N., Vandenberg, S. G., and Wilson, J. R. (1976a). Parent-offspring resemblance for specific cognitive abilities in two ethnic groups. *Nature* **261**:131–133.

DeFries, J. C., Vandenberg, S. G., and McClearn, G. E. (1976b). Genetics of specific cognitive abilities. *Annu. Rev. Genet.* **10**:179–207.

DeFries, J. C., Johnson, R. C., Kuse, A. R., McClearn, G. E., Polovina, J., Vandenberg, S. G., and Wilson, J. R. (1979). Familial resemblance for specific cognitive abilities. *Behav. Genet.* **9**:23–43.

Faubian, R. W., Cleveland, E. A., and Hassell, T. W. (1942). The influence of training on mechanical aptitude test scores. *Educ. Psychol. Meas.* **2**:91–94.

French, J. W., Ekstrom, R. B., and Price, L. A. (1963). *Manual for Kit of Reference Tests for Cognitive Factors*, Educational Testing Service, Princeton, N.J.

Gesell, A., Halverson, H. M., Thompson, H., Ilg, F. L., Castner, B. M., Ames, L. B., and Amatruda, C. S. (1940). *The First Five Years of Life: A Guide to the Study of the Preschool Child*, Harper and Row, New York.

Hartlage, L. C. (1970). Sex-linked inheritance of spatial ability. *Percept. Motor Skills* **31**:610.

Hyde, J. S. (1981). How large are cognitive gender differences? A meta-analysis using W^2 and d. *Am. Psychol.* **86**:892–901.

Jardine, R., and Martin, N. G. (1983). Pedigree analysis of spatial ability (submitted for publication).

Kolakowski, D., and Malina, R. M. (1974). Spatial ability, throwing accuracy and man's hunting heritage. *Nature* **251**:410–412.

Loehlin, J. C., Sharan, S., and Jacoby, R. (1978). In pursuit of the "spatial gene": A family study. *Behav. Genet.* **8**:27–41.
Maccoby, E. E., and Jacklin, C. N. (1974). *The Psychology of Sex Differences*, Stanford University Press, Stanford, Calif., pp. 25–55.
Martin, N. G., and Eaves, L. J. (1977). The genetical analysis of covariance structure. *Heredity* **38**:79–95.
Masica, D. N., Money, J., Ehrhardt, A. A., and Lewis, V. G. (1969). IQ, fetal sex hormones and cognitive patterns: Studies in the testicular feminizing syndrome of androgen insensitivity. *John Hopkins Med. J.* **124**:34–43.
McGee, M. G. (1978). Effects of training and practice on sex differences in Mental Rotation Test scores. *J. Psychol.* **100**:87–90.
McGee, M. G. (1979). Human spatial abilities: Psychometric studies and environmental, genetic, hormonal and neurological influences. *Psychol. Bull.* **86**:889–918.
Michael, W. B., Guilford, J. P., Fruchter, B., and Zimmerman, W. S. (1957). The description of spatial-visualization abilities. *Educ. Psychol. Meas.* **17**:185–199.
Money, J., Alexander, D., and Walker, H. T., Jr. (1965). *A Standardized Road-Map Test of Direction Sense*, Johns Hopkins Press, Baltimore.
Park, J., Johnson, R. C., DeFries, J. C., McClearn, G. E., and Mi, M. P. (1978). Parent-offspring resemblance for specific cognitive abilities in Korea. *Behav. Genet.* **8**:43–52.
Porteus, S. D. (1965). *Porteus Maze Test: Fifty Years' Application*, Pacific Books, Palo Alto, Calif.
Smith, I. M. (1948). Measuring spatial abilities in school pupils. *Occupat. Psychol.* **22**:150–159.
Stafford, R. E. (1961). Sex differences in spatial visualization as evidence of sex-linked inheritance. *Percept. Motor Skills* **13**:428.
Thomas, H., Jamison, W., and Hummel, D. D. (1973). Observation is insufficient for discovering that the surface of still water is invariantly horizontal. *Science* **181**:173–174.
Walker, J. T., Krasnoff, A. G., and Peaco, D. (1981). Visual spatial perception in adolescents and their parents: The X-linked recessive hypothesis. *Behav. Genet.* **11**:403–413.
Yen, W. M. (1975). Sex-linked major-gene influences on selected types of spatial performance. *Behav. Genet.* **5**:281–298.

Edited by Thomas J. Bouchard, Jr.