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Sex Differences in Spatial Abilities Among Adults from the United States and China

Implications for Evolutionary Theory

Abstract

Sex differences on tests of spatial abilities were examined for two samples of adults from the United States (U.S.) and China. In Study 1, an inconsistent pattern of sex differences emerged for tests that largely required subjects to mentally rotate representations of geometric figures in two dimensions. A male advantage on the Mental Rotation Test (MRT), a test that requires subjects to mentally rotate representations of geometric figures in three dimensions, was found for both the U.S. (n = 66) and Chinese (n = 40) samples. Study 2 included larger samples and replicated the sex difference on the MRT. It was also shown that in both the U.S. (n = 237) and China (n = 218), males were over-represented at the high end of MRT scores, and females were over-represented at the low end of MRT scores. The results support the position that the male superiority in 3-dimensional spatial cognition is not dependent upon culture.

Key words

Sex differences, spatial abilities, evolution, culture.

A male advantage in the ability to generate and mentally manipulate spatial representations of geometric and other figures has been well established in studies conducted in North America and in a host of European nations (GEARY 1998; KIMURA 1999; LINN/PETERSON 1985; MASTERS/SANDERS 1993; VOYER/VOYER/BRYDEN 1995), including Austria (RESCHER/RAPPELSBERGER 1999), England (MCGOWAN/DUKA 2000), Germany (HAUSMANN et al. 2000), Hungary (KARADI et al. 1999), Norway (AMPONSAH/KREKLING 1997), Scotland (JAHODA 1979, 1980), and Sweden (HERLITZ/AIRAKSINEN/NORDSTROEM 1999). AMPONSAH, KREKLING and JAHODA found the same sex differences in Ghana, as did HALPERN/TAN (2001) in Turkey. Across these nations, the sex difference is particularly robust on tests of 3-dimensional spatial cognition (see also MOFFAT/HAMPSON/HATZIPANTELIS 1998), and is especially robust for the Mental Rotation Test (MRT; VANDENBERG/KUSE 1978). For less difficult and other forms of spatial task the pattern of sex differences is more mixed, although a male advantage is common (KIMURA 1999; EALS/SILVERMAN 1994; SILVERMAN/EALS 1992).

In any case, the finding of a robust cross-national male advantage on the MRT has been interpreted as consistent with evolutionary theory (GEARY 1995, 1996, 1998). Specifically, aspects of male–male coalitional competition (e.g., warfare; GEARY 1998) and other sex differentiated activities (e.g., hunting; SILVERMAN/EALS 1992; SILVERMAN et al. 2000) result in more navigation in unfamiliar territory for males than for females in preindustrial societies and presumably throughout human evolution. Sex differences in activities that involve a differential use of 3-dimensional physical space should, in theory, result in the evolution of sex differences in the cognitive and brain systems that enable navigation in and the mental representation of this space (GAULIN 1992; GAULIN/FITZGERALD 1989; GEARY 1995; SILVERMAN et al. 2000). A detailed analysis of the cognitive mechanisms supporting MRT performance suggests that items on the MRT may engage some of the same cognitive (and presumably brain) systems that support navigation in and the representation of 3-dimensional space (JUST/CARPENTER 1985, p165). Indeed, MOFFAT et al. found a large male advantage in the ability to navigate in a 3-dimensional virtual maze and that performance on the maze task was significantly correlated with MRT performance. SILVERMAN et al. found that males were better than females at wayfinding in an unfamiliar wooded area (i.e. knowing one's position in the area, relative to a start point) and that wayfinding performance was correlated with MRT performance, although DABBS and his colleagues reported that MRT performance was not correlated with performance on a paper-and-pencil navigation task (DABBS et al. 1998).

At this point, the relation between sex differences on the MRT and human sex differences, favoring males, in the ability to navigate in a novel 3-dimensional environment remains to be clarified (GEARY 1998; MOFFAT/HAMPSON/HATZIPANTELIS 1998). Nonetheless, it is clear that MRT performance is related to prenatal exposure to and circulating levels of sex hormones (e.g., GAULIN et al. 1997; HAMPSON 1990; HAUSMANN et al. 2000; MCCORMICK/TEILLON 2001; RESNICK et al. 1986; SILVERMAN/PHILIPS 1993; for a review see KIMURA 1999). The relation between sex hormones and MRT performance is, of course, in keeping with the view that the sex difference on this task reflects a more fundamental sex difference in the cognitive and brain systems that support 3-dimensional spatial cognition. The relation is also in keeping with the evolutionary model, as sex hormones are one of the primary mechanisms involved in the proximate expression of evolved sex differences (GEARY 1998).

Despite a clear theoretical rationale for expecting sex differences in complex spatial abilities and evidence that these differences are found across cultural context and covary with levels of sex hormones, CAPLAN/CRAWFORD (1997) recently asserted that sex differences in spatial ability, when they are found, are due to differences in the treatment of males and females and not to biological or evolutionary mechanisms. The above mentioned pattern of sex differences across many different national and cultural contexts argues against this position. Still, the proposition that the male advantage in 3-dimensional spatial abilities is a universal and evolved sex difference would be further bolstered with the demonstration that these differences are evident in East Asian, as well as North American, European, and African nations. However, it appears that sex differences on the MRT have only been assessed in one East Asian population, samples of high-school students from Japan (MANN et al. 1990; SILVERMAN/PHILLIPS/SILVERMAN 1996). In both studies, males outperformed females on the MRT in the Japanese and in U.S. samples. MANN et al. found no sex differences on a second spatial test—the Mazes subtest of the WECHSLER Intelligence Scale for Children–Revised (WECHSLER 1974)—in either nation, and SILVERMAN et al. found only a modest sex difference, favoring males, on a test of 2-dimensional spatial cognition. The results of MANN et al. and SILVERMAN et al. are consistent with a common finding that males outperform females on the MRT and that the pattern of sex differences is often more mixed for less complex spatial measures.

The current analyses were conducted as a response to CAPLAN/CRAWFORD'S (1997) denial of innate sex differences in spatial abilities, and in light of the paucity of information on spatial sex differences in East Asian populations. In the first study, we compare the pattern of sex differences on the MRT, and two other spatial tests, for samples of young adults from the U.S. and mainland China, and in the second assess sex differences on the MRT for larger Chinese and American samples. These comparisons provide an opportunity to replicate the sex difference on the MRT reported by MANN et al. (1990) and SILVERMAN/PHILLIPS/SILVERMAN (1996) for Japanese adolescents. In addition to providing another much needed assessment of sex differences in East Asia, a replication with Chinese samples is important in and of itself. This is because previous cross-national research suggests that individuals from Japan outperform individuals from China and the U.S. on tests of spatial abilities (MANN et al. 1990; SILVERMAN/PHILLIPS/SILVERMAN 1996; STEVENSON et al. 1985), indicating that it cannot be concluded that the sex difference on the MRT in Japan will generalize to other Asian nations. Moreover, unlike Japan, the cultural ethos in mainland China is that of equality of the sexes. Thus, if CAPLAN/CRAWFORD'S (1997) position is correct then a sex difference should not be found on the MRT in China.

Study 1

As noted, the goal was to examine the pattern of sex differences on a battery of spatial ability tests administered to college students in the U.S. and China, as part of a larger study of cross-national differences in arithmetical competencies (GEARY et al. 1996); sex differences were not analyzed as part of the larger study. Of particular theoretical interest is the question of whether the male advantage on the MRT will be found in China.

Methods

Subjects. The subjects were 40 (20 female, 20 male; age range 17 to 22 years) adults from China, and 66 (42 female, 24 male; age range 18 to 42 years) adults from the U.S. The American adults were recruited from undergraduate psychology courses at the University of Missouri, Columbia, and the Chinese adults were recruited from undergraduate courses at East China Normal University, Shanghai, China. The mean age was 19 (*SD* = 1) and 20 (*SD* = 4) years, respectively, for the Chinese and American samples ($p < .05$).

Ability Measures. All subjects were administered a battery of psychometric tests that spanned the Numerical Facility, Perceptual Speed, and Spatial Orientation ability factors (EKSTROM/FRENCH/HARMAN 1976), although only scores on the spatial tasks are considered here; cross-national differences are described in GEARY et al. (1996). The spatial tests included the Card Rotations Test and the Cube Comparisons Test, both from the Educational Test Service battery of factor-referenced tests, as well as the MRT (EKSTROM/FRENCH/HARMAN 1976; VANDENBERG/KUSE 1978). For each form of all three tests, subjects were allowed 3 min to match rotated test figures against a comparison figure. The Card Rotations Test requires the rotation of figures in 2-dimensional space, whereas the MRT requires the rotation of figures in 3-dimensional space. The Cube Comparisons Test requires the rotation of drawings of cubes, some of which need to be rotated in 2-dimensional space, others in 3-dimensional space. For each test, the score was the number of items correctly identified minus the number of items incorrectly identified (to correct or guessing).

Procedure. Translation. For all measures, the test stimuli were identical in the English and Chinese versions. To ensure comparability, an experienced translator first translated the English instructions into Chinese. Another experienced translator who was not familiar with the English instructions then back translated the Chinese version into English. Discrepancies between the original English instructions and the back-translated instructions were then discussed between the first author and the two translators, which resulted in a second Chinese version of the instructions. To ensure that these instructions were clear, the Chinese versions of all ability measures were then administered to two individuals who were not familiar with either the English or Chinese versions of the tests. Both individuals indicated that the instructions were readily understandable.

Administration. All ability measures were administered in small groups and under standard instructions. The entire testing session lasted about 50 min.

	United States				China			
	Male		Female		Male		Female	
Test	M	SD	M	SD	M	SD	M	SD
	Study 1							
CR	117	21	115	28	99	31	90	24
CC	21	10	14	9	12	8	15	9
MRT	21	9	12	8	16	11	12	9
	Study 2							
MRT	18	10	13	8	19	9	13	7

Table 1. Mean cross-national and sex differences for tests of spatial cognition.

Results

Mean test scores across nation and sex are shown in the top portion of Table 1. Scores on each test were submitted to a 2 (nation) by 2 (sex) analysis of variance. For the Card Rotations Test, neither the main effect for sex ($F(1,102) < 1$) nor the nation by sex interaction were significant ($F(1,102) < 1$), although the scores for the U.S. sample were higher than those for the Chinese sample ($F(1,102) = 15.83$, $p < .001$). For the Cube Comparisons Test, the main effect for sex was not significant ($F(1,102) = 1.21$, $p > .25$), but main effect for nation ($F(1,102) = 4.82$, $p < .05$) and the nation by sex interaction was ($F(1,102) = 6.62$, $p < .05$). Examination of Table 1 reveals that males had higher Cube Comparisons Test scores in the U.S. sample, but females had higher scores in the Chinese sample. Follow-up analyses revealed that the sex difference was significant for the U.S. sample ($F(1,102) = 8.22$, $p < .01$), but not for the Chinese sample ($F(1,102) < 1$). Finally, the main effect for sex, favoring males in both samples, was significant for the MRT ($F(1,102) = 14.55$, $p < .001$), but the main effect for nation ($F(1,102) = 2.15$, $p > .10$) and nation by sex interaction was not ($F(1,102) = 1.55$, $p > .20$).

Discussion

The findings for the Card Rotations Test and the Cube Comparisons Test suggest that for spatial tasks that largely require the mental rotation of 2-dimensional geometric figures, there may be no sex differences, or a different pattern of sex differences depending on culture or the particular sample assessed. These findings may not, however, generalize to more complex 2-dimensional spatial tasks, as COLLINS/KIMURA (1997) found a large male advantage for a 2-dimensional task that was more complex than the tests used in this study. In any case, the sex difference, favoring males, in the ability to mentally rotate 3-dimensional representations of geometric figures (i.e., MRT performance) was evident for young adults from both the U.S. and China. Moreover, the finding of a nonsignificant nation by sex interaction for the MRT indicated that the size of the male advantage did not differ across samples. Although the findings for the MRT are of theoretic interest, as noted earlier, they are in need of replication, given the small sample sizes.

Study 2

To assess further the cross-national sex difference for performance on the MRT, data from additional samples of young adults from the U.S. and China were re-analyzed (GEARY et al. 1999). As with the first study, the goal of the original research was to assess the pattern of cross-national differences in arithmetical competencies. The MRT was included as a contrast measure, that is a measure, unlike mathematical tests, for which there do not appear to be national differences comparing adults from the U.S. and China.

Methods

Subjects. The subjects were 237 (113 male, 123 female; one participant did not provide information on sex; 84% Caucasian) general psychology students from the University of Missouri, Columbia, and 218 (108 male, 110 female) undergraduate students from East China Normal University, Shanghai, China. The U.S. students received partial course credit for participating in the study, whereas the Chinese students received a small payment. The mean age of both samples was 19 years.

Ability Measures and Procedure. In addition to the MRT, all subjects were administered a battery of arithmetical computation and arithmetical reasoning tests, as well as an intelligence test; no other spatial tests were administered. The same translation and administration procedures described for Study 1 were followed (see GEARY et al. 1999).

Results

Mean sex differences. As shown in the bottom portion of Table, the pattern of cross-natoinal performance and sex differences replicates that found for Study 1. More precisely, neither the main effect for nation (F (1, 450) = 1.05, p > .25) nor the nation by sex interaction (F,1,450) = 1.05, p.>.25) were significant, but the main effect for sex was, (F(1,450) = 58.77, p < .0001).

Sex differences in high and low scores. The relatively large sample sizes allowed for an assessment of sex differences at the high and low ends of the distributions of MRT scores. For the U.S. sample, 75% (45 of 60) of the individuals in the top quartile were male, whereas 68% (40 of 59) of the individuals in the bottom quartile were female ($\chi^2(1) = 21.92$, $p < .001$). For the Chinese sample, 72% (41 of 57) of the individuals in the top quartile were male, and 72% (44 of 61) of the individuals in the bottom quartile were female ($\chi^2(1) = 22.89$, $p < .001$). The same trend was found for comparisons of the top and bottom deciles. For the US sample, 86% (24 of 28) of the individuals in the top decile were male, whereas 63% (15 of 24) of the individuals in the bottom decile were female ($\chi^2(1) = 12.96$, $p < .001$). For the Chinese sample, 81% (22 of 27) of the individuals in the top decile were male, and 64% (18 of 28) of the individuals in the bottom decile were female ($\chi^2(1) = 11.83$, $p < .001$).

Discussion

The cross-national sex difference, favoring males, on the MRT was replicated, and it was demonstrated that for both the U.S. and Chinese samples the majority of high scoring individuals were male and the majority of low scoring individuals were female. The differences were especially pronounced at the high end of the distributions of MRT scores. In the top ten percent of scores, the ratio of males to females was 6:1 in the U.S. sample and 4.4:1 in the Chinese sample. In the bottom 10 percent of scores, there were more than three females for every two males in the U.S. sample (female to male ratio of 1.67:1) and nearly two females for every male in the Chinese sample (female to male ratio of 1.8:1).

Summary and General Discussion

A male advantage on the MRT was found for young adults from the U.S. and China, and the magnitude of this sex difference did not differ across nations. The results are in keeping with the findings of MANN et al. (1990) and SILVERMAN/PHILLIPS/SILVERMAN (1996) of a male advantage on the MRT for samples of Japanese high-school students, and consistent with similar studies conducted in North America, Europe, and Africa (e.g., MCGOWAN/DUKA 2000; VOYER/VOYER/BRYDEN 1995). The current results thus confirmed the robustness of the male advantage on the MRT, and cast doubt upon the position that the sex difference in 3-dimensional spatial cognition is due to cultural factors or to differences in the treatment of males and females (CAPLAN/CRAWFORD 1997). The results for China are especially difficult to reconcile with CAPLAN and CRAWFORD's views, given the social ethos of equality of the sexes.

The sex difference, of course, does not mean that MRT performance, or spatial abilities in general, are not influenced by exploration of and navigation in physical space, as such exploration and other spatial-related experiences are clearly related to improved spatial abilities (MATTHEWS 1992). Rather, it is most likely that the male advantage on the MRT arises from both hormonal and experiential factors, and that the same hormonal mechanisms that facilitate spatial performance are likely to prompt males and females to differentially engage physical space. The sex difference, favoring males, in engagement in physical space, such as exploration of unfamiliar areas (see MATTHEWS 1992), is likely to interact with hormonal influences on the cognitive and brain systems that support spatial cognition to produce the observed differences (GEARY 1998).

Although the data do not directly address the position that male–male competition (e.g., warfare) and other sex-differentiated activities (e.g., hunting) has resulted in the evolution of a male advantage in 3-dimensional spatial competencies (GEARY 1998; SILVERMAN et al. 2000; SILVERMAN/EALS 1992), they are consistent with this position. Stated otherwise, the current studies provided an opportunity, especially in light of the ethos of sexual equality in mainland China, to reject the evolutionary hypothesis. That the hypothesis was not rejected provides further support for the view that the male advantage in complex spatial cognition has a biological basis, and makes cultural (e.g., stereotypes) models of these sex differences increasingly untenable (see also HALPERN/TAN 2001).

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Acknowledgments

We would like to thank Guo-Peng CHEN, Melissa MOON, and Ravindran SABAPATHY for their assistance with data collection and collation, and Fan LIU and Zhitang LIU for their assistance with the translations. The research was supported by grant 1R01-HD27931 from the National Institute of Child Health and Human Development and a grant from the Research Board of the University of Missouri, both awarded to the first author.

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