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Sex Differences in Mental Rotation and Line Angle Judgments Are Positively Associated with Gender Equality and Economic Development Across 53 Nations

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Abstract Mental rotation and line angle judgment performance were assessed in more than 90,000 women and 111,000 men from 53 nations. In all nations, men's mean performance exceeded women's on these two visuospatial tasks. Gender equality (as assessed by United Nations indices) and economic development (as assessed by per capita income and life expectancy) were significantly associated, across nations, with larger sex differences, contrary to the predictions of social role theory. For both men and women, across nations, gender equality and economic development were significantly associated with better performance on the two visuospatial tasks. However, these associations were stronger for the mental rotation task than for the line angle judgment task, and they were stronger for men than for women. Results were discussed in terms of evolutionary, social role, and stereotype threat theories of sex differences.

Keywords Evolutionary theory · Sex differences · Social role theory · Stereotype threat theory · Visuospatial ability

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Introduction

Many kinds of visuospatial performance show consistent, on-average sex differences. For example, men tend to score higher than women on tests of mental rotation and on tests of spatial perception and orientation (Halpern et al., 2007; Voyer, Voyer, & Bryden, 1995), whereas women tend to score higher than men on tests of memory for object locations in spatial arrays (Ecuyer-Dab & Robert, 2004; Silverman & Phillips, 1998). Explanations for such differences have focused on a number of possible causal factors, including distal factors (e.g., biological evolution, the cultural evolution of gender roles) and more proximate causes (e.g., the effects of sex-linked abilities and interests, prenatal and post-pubertal sex steroid hormones, gender roles, gender socialization, and gender stereotypes).

Evolutionary theorists have proposed that selection pressures on early humans led to sex differences in some spatial abilities (e.g., see Buss, 1999; Geary, 1998). For example, ancestral men's specialization in tracking, hunting, targeting, and projectile throwing may have favored the development of three-dimensional visualization skills and the ability to visually track and target moving objects, whereas ancestral women's specialization in foraging may have favored the development of accurate memory for object locations and skill in locating foraging sites in relation to geographic landmarks. At a more proximate level of biological analysis, sex-linked genetic factors may contribute to sex differences in visuospatial abilities through their effects on the action of sex hormones at various stages of development. Indeed, several strands of research suggest that exposure to sex steroids during both early (prenatal and perinatal) life and after puberty may be linked to performance on certain visuospatial tasks (Halpern et al., 2007). Consistent with hormonal theories of sex-linked visuospatial performance

are findings that homosexual individuals sometimes differ from same-sex heterosexual individuals, with homosexual men showing more female-typical and lesbians more male-typical levels of performance on some visuospatial tasks (Collaer, Reimers, & Manning, 2007; Peters, Manning, & Reimers, 2007).

A number of social-environmental theories are also relevant to sex differences in visuospatial abilities. Social role theory proposes that psychological sex differences result from men's and women's different family and work roles in modern societies (Eagly & Wood, 1999; Wood & Eagly, 2002), and it predicts that people in societies with strong, polarized gender roles will display larger sex differences than those in societies with weaker, less polarized gender roles. Overlapping with social role theory, gender socialization theories propose that in virtually all societies, boys and girls are subject to different socialization pressures, which sometimes result in psychological sex differences (Ruble & Martin, 1998). For example, gender socialization may lead boys more than girls to play team sports and video games and to practice carpentry and car repair—activities that develop specific spatial competencies. Some social psychological theories suggest that gender stereotypes may lead to self-fulfilling prophecies, with men and women conforming to societal expectations about the stereotypic abilities attributed to their sex (e.g., Lott & Maluso, 1993), whereas others propose that stereotypes about sex differences in abilities can undermine, under certain circumstances, the performance of the sex believed to have lesser ability (Spencer, Steele, & Quinn, 1999; Steele, 1997).

One way to test biological and social-environmental explanations of psychological sex differences is to assess the cross-cultural consistency of sex differences and to investigate whether the sex differences are associated, across societies, with the strength of societies' gender roles (Eagly & Wood, 1999; Lippa, 2005, in press). If sex differences are consistent across cultures and, furthermore, if they are unrelated to the strength of societies' gender roles, then the case for biological influences is bolstered. In contrast, if the direction of sex differences varies across societies—with men exceeding women in some societies, women exceeding men in others, and no differences in still others—then the predictions of biological theories of sex differences are contradicted. In addition, if sex differences covary with the strength of societies' gender roles, such that larger sex differences are associated with stronger gender roles, then social role and gender socialization theories garner support.

A number of recent studies have examined cross-cultural patterns of sex differences in traits such as self-reported personality, emotions, and values, and these studies have often yielded the unexpected result that sex differences tend to be larger in gender egalitarian, economically developed nations than in gender non-egalitarian, less developed nations (Guimond, 2007). Several theories have been offered to explain these counter-intuitive findings. Among them are: (1) attributional theories (e.g., men and women in countries with strong gender roles tend to attribute their differing behaviors to powerful gender roles rather than to internal dispositions, whereas the reverse is true in countries with weaker gender roles; see Costa, Terracciano, & McCrae, 2001); (2) social comparison theories (e.g., when self-reporting personality traits, men and women in countries with strong gender roles tend to compare themselves to in-group members—i.e., members of their own sex—whereas men and women in countries with weaker gender roles compare themselves more to people in general; see Guimond et al., 2007); and (3) evolutionary theories that hypothesize an interaction between evolved sex-linked dispositions and environmental affordances (e.g., the difficult environments more often found in less developed countries may limit both male and female development, thereby reducing some sex differences, whereas the more facilitative environments in developed, gender egalitarian countries may encourage optimal development in both sexes, with the result that divergent innate predispositions are more fully expressed; see Schmitt, Realo, Voracek, & Allik, 2008).

Attributional and social comparison theories would seem to apply more readily to sex differences in self-reported personality, emotions, and values than to sex differences in cognitive abilities. For example, when rating themselves on personality traits such as "aggressiveness," men and women might reasonably ask, "Compared to whom?", and they might plausibly attribute their recalled aggressive behaviors either to strong societal gender roles or to internal dispositions. However, when taking cognitive ability tests, individuals attempt to answer test questions correctly, not to report their traits or to attribute the causes of their recalled modal behaviors.

Although attributional and social comparison theories may be less relevant to sex differences in cognitive abilities than to sex differences in other kinds of psychological traits, one social psychological theory is highly relevant to sex differences in cognitive performance—namely, the theory of stereotype threat (Good, Aronson, & Harder, 2008; Shih, Pittinsky, & Ambady, 1999; Spencer et al., 1999; Steele, 1997). According to this theory, negative stereotypes about the cognitive abilities of one sex (e.g., women's math ability) can lead members of that sex to experience anxiety and intrusive thoughts in test-taking situations, particularly when gender is made salient and when high levels of performance are important to the individual. To explain cross-cultural variations in sex differences in ability, stereotype threat theory requires additional assumptions—for example, that stereotypes about the relative abilities of men and women are stronger in some societies than others, that gender stereotypes are more salient to individuals in some societies than others,

or that high levels of performance are more important to individuals in some societies than others.

A priori, one reasonable hypothesis is that members of gender egalitarian, economically developed societies will tend to hold weaker stereotypes about sex differences in ability than members of gender non-egalitarian, less economically developed societies will. The rationale for this hypothesis is twofold. First, the gender egalitarian ideologies more commonly found in gender egalitarian societies tend to minimize sex differences in ability. Second, to the extent that men and women occupy more diverse roles in gender egalitarian, economically developed countries (e.g., women are physicians and lawyers as well as nurses and secretaries), members of such societies should associate gender with ability less strongly than members of more gender non-egalitarian societies do. If the previous assumptions are correct, then the debilitating effects of gender stereotypes on women's test performance should be stronger in gender non-egalitarian than gender egalitarian societies, leading to larger sex differences in these societies.

Also reasonable, but leading to different predictions, are the hypotheses that women in more developed, gender egalitarian societies may be exposed more often to scientific research on sex differences in cognitive performance leading to more pervasive stereotypes (e.g., see Dar-Nimrod & Heine, 2006; Eccles & Jacobs, 1986) and that women in more developed, gender egalitarian societies have a stronger desire to perform well on stereotypically male-favored tasks than women in less developed, gender non-egalitarian societies. If these assumptions are correct, then the debilitating effects of gender stereotypes on women's test performance may be stronger in gender egalitarian than in gender non-egalitarian societies, leading to larger sex differences in these societies.

Although opposing predictions about systematic cross-cultural variation in sex differences in performance can be derived from stereotype threat theory, depending on additional assumptions, the theory nonetheless seems to imply that women's performance on stereotypically male-favored tasks will vary systematically across societies more than men's performance, because women, not men, are theorized to experience the performance-undermining thought processes resulting from negative gender stereotypes.

In the research reported here, we extended previous research on the cross-cultural consistency of sex differences by examining, across 53 nations, patterns of sex differences in two sex-linked cognitive domains: mental rotation performance and line angle judgment performance. In addition to examining the cross-nation consistency of these sex differences, we also explored whether national indices of gender equality and economic development were related to sex differences in performance and, also, to mean male and female levels of performance on these two visuospatial tasks.

Method

Participants

From February through May 2005, the British Broadcasting Corporation (BBC) conducted an Internet survey on human sex differences for use in its documentary, *Secrets of the Sexes*. A total of 255,114 people responded to at least some items in each of the six sections of the survey. Most of these participants reported their sex and other demographic information and completed a six-item mental rotation test and a 20-item line angle judgment test.

Fifty-three nations in the BBC data set had total samples of 90 or more participants, and the cross-nation analyses reported here focus on these samples. Analyses were restricted to participants who were at least 18 years of age and no older than 80 years of age. The large majority of participants in the BBC survey were young adults 18–40 years of age (see Reimers, 2007). In the current analyses, national samples of men with usable mental rotation scores ranged in size from 52 to 43,783, with a median sample size of 206 and a total sample size of 111,350. National samples of women ranged in size from 19 (36, when the smallest sample—Saudi Arabian women—was excluded) to 36,714, with a median sample size of 169 and a total sample size of 90,433. National samples of men who had usable line angle judgment scores ranged in size from 52 to 54,016, with a median sample size of 217 and a total sample size of 116,368. National samples of women ranged in size from 18 (30, when Saudi women were excluded) to 42,028, with a median sample size of 175 and a total sample size of 95,364. All male samples and all but three female samples included more than 40 individuals.

Measures

Mental Rotation and Line Angle Judgment Tasks

A short, six-item mental rotation test (Peters et al., 1995), similar to that of Vandenberg and Kuse (1978), was implemented in HTML and presented to participants in a pop-up window. Participants viewed a block object diagram to the left of the screen and were asked which two of four diagrams to the right of the screen showed the same object "viewed from a different angle." Participants were instructed to click on two of the four comparison diagrams that were correct answers. Participants had 150 s to complete the entire task and could allot time among the six questions as they wished. A countdown timer on the bottom of the screen showed the amount of time that remained after participants started the task. Performance was scored by awarding a single point for each correct answer chosen, thus yielding a total score that could range from 0 to 12. Mental rotation measures typically show moderate to large sex differences favoring men (Voyer

et al., 1995). For further methodological details about the BBC mental rotation task, see Peters et al. (2007).

The 20-item line angle judgment task was adapted from Collaer (2001) and Benton, Varney, and Hamsher (1978). Similar tasks have shown large sex differences favoring men in laboratory research (Cherney & Collaer, 2005; Collaer & Nelson, 2002). The BBC survey line angle task was implemented as an Adobe Flash movie. Participants viewed a "target line" at the top of the screen, which was displayed in one of 14 angled orientations ranging, in roughly 12.9 degree increments, from horizontal to vertical and back to horizontal, spanning 180 degrees. Beneath the target line was a "fan" of 15 lines that assumed all possible angular orientations. The participant's task, on each trial, was to pick from the set of 15 choices the line that matched the angular orientation of the target line. Participants selected a matching line by clicking on one of the 15 lines in the bottom array. Participants had 10 s to complete each item and the elapsed time for each item was shown by a countdown timer at the bottom of the screen. If a participant failed to respond within the allotted time, a response of "blank" was recorded, which was treated as a wrong answer. A participant's accuracy score was the number of items out of 20 answered correctly. For additional methodological details, see Collaer et al. (2007). In the BBC survey, the line angle judgment task preceded the mental rotation task.

Gender Equality and Economic Development

Statistics for United Nations gender-related development and gender empowerment indices were taken from the United Nations 2005 and 2001 Human Development Reports (available at: http://hdr.undp.org/statistics/data/). The UN gender-related development index assessed nations' gender equity on three dimensions: health and longevity, standard of living, and knowledge and education. The UN gender empowerment measure assessed nations' gender equity on three power dimensions: power over economic resources, participation in economic decision making, and participation in political decision making. In several cases, when 2005 statistics were not available for given nations, we used 2001 statistics instead. United Nations gender empowerment statistics were not available for six of the 53 nations studied here. Two indices of economic development were also obtained from UN Human Development reports: nations' per capita income in U.S. dollars and life expectancy. The four indices tended to be strongly correlated (rs ranged from .68 to .84, all ps $< .001$), indicating that nations that were high on gender equality also tended to be high on economic development.

Demographic Control Variables

Previous analyses of the BBC data showed that performance on the mental rotation and line angle judgment tasks was related to participants' age and education levels, although sex effects tended to be considerably larger than age and education effects (Collaer et al., 2007; Peters et al., 2007). Because national samples may have varied in their mean ages and education levels, we used in some analyses the following control variables computed for each nation: percent of men with greater than high school education, percent of women with greater than high school education, ratio of percent of men to percent of women with greater than high school education, mean age of men, mean age of women, and ratio of men's mean age to women's mean age.

Results

Consistency of Sex Differences Across Nations

Sex differences in mental rotation and line angle judgment performance were universally present across nations, with men's mean scores always exceeding women's mean scores (see Figs. 1, 2). A paired-data t-test comparing men's and women's mean mental rotation scores across nations showed a significant sex difference, $t(52) = 22.67$, $p < .001$, $M = 8.16$ for men and 7.00 for women, mean of 53 national ds $= .47$. Similarly, a paired-data t-test comparing men's and women's mean line angle judgment scores across nations showed a significant sex difference, $t(52) = 23.93, p < .001$, $M = 15.54$ for men and 14.07 for women, mean of 53 national ds $= .49$.

Correlations Between National Indices and Spatial Performance Parameters

Table 1 presents correlations between national indices of gender equality and economic development and three mental rotation parameters: men's means, women's means, and sex differences. UN gender development and empowerment indices and life expectancy were significantly correlated with sex differences in mental rotation performance, with higher levels of gender equality and economic development associated with larger sex differences. Partial correlations that controlled for variations in age and education across samples showed that two of three correlations remained significant after controlling for these factors. Across nations, indices of gender equality and economic development were strongly correlated with men's and women's mean performance on the mental rotation task, such that greater gender equality and economic development were associated with better performance.

Table 2 presents correlations between national indices of gender equality and economic development and three line angle judgment parameters: men's means, women's means, and sex differences. All UN gender equality indices and

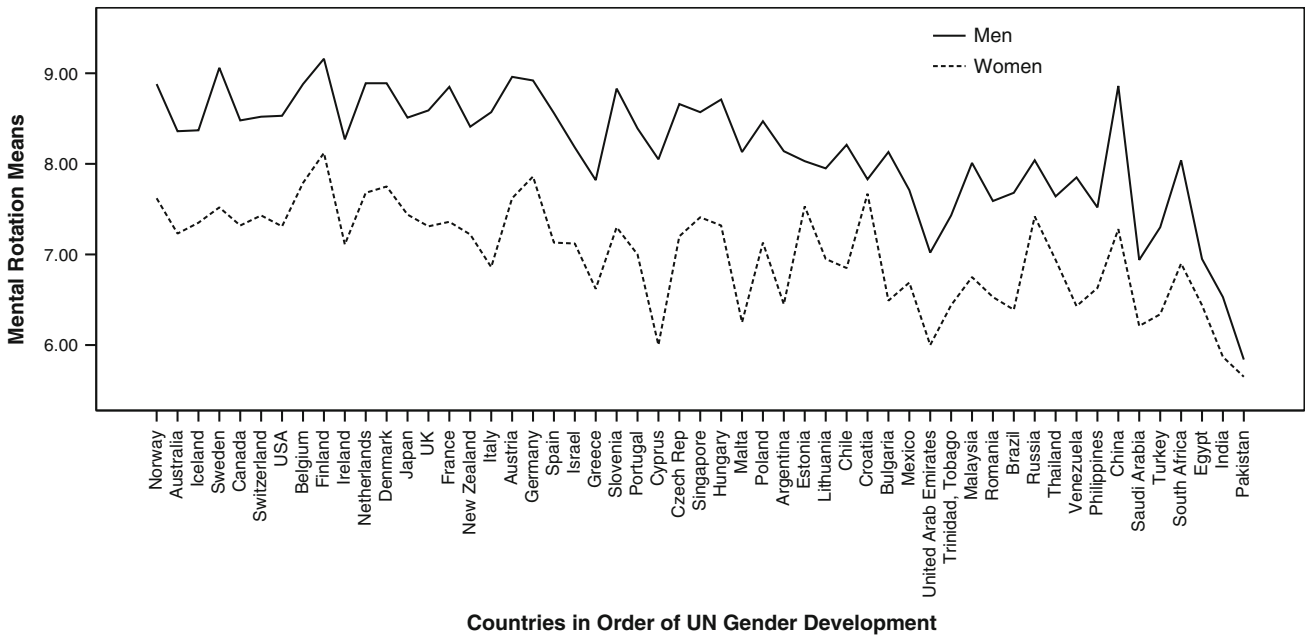

Fig. 1 Men's and women's mental rotation means across 53 nations listed in order of their UN gender development score (with the most gender egalitarian nations at the left and least egalitarian at the right)

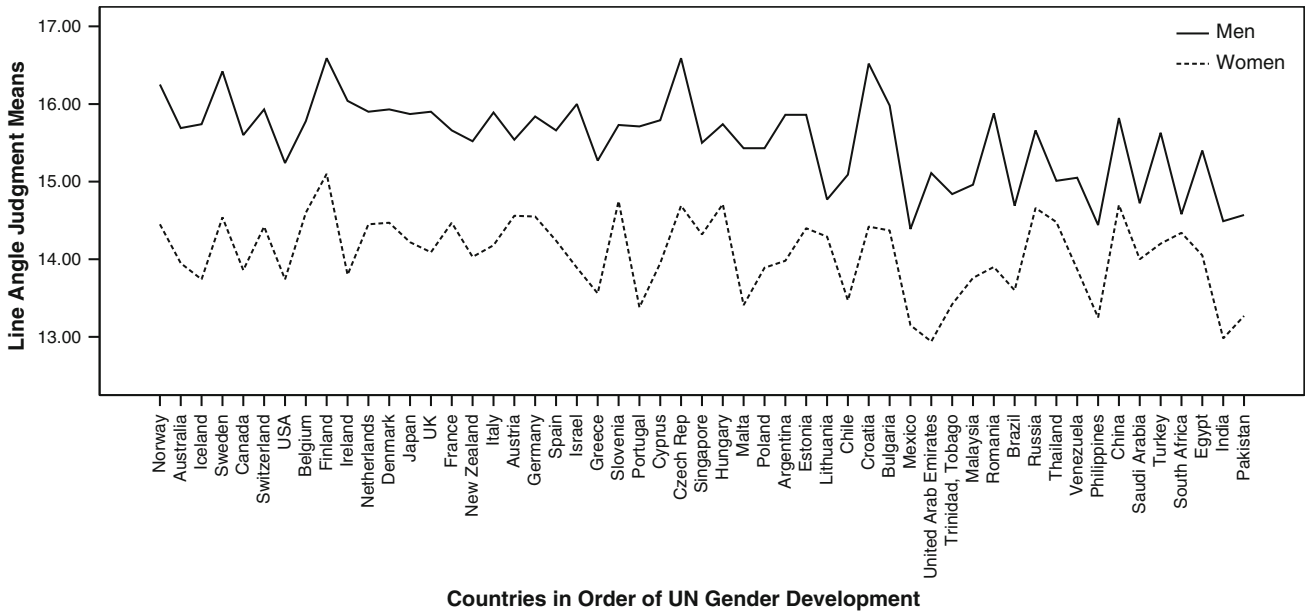

Fig. 2 Men's and women's line angle judgment means across 53 nations listed in order of their UN gender development score (with the most gender egalitarian nations at the left and least egalitarian at the right)

indices of economic development were significantly correlated with sex differences in line angle judgment performance, with higher levels of gender equality and economic development associated with larger sex differences. These correlations remained significant after controlling for variations in age and education across samples. National indices of gender equality and economic development were significantly correlated with mean performance on the line angle judgment task. However, these correlations tended to be smaller than the corresponding correlations for mental rotation performance, and correlations for men tended to be larger than those for women.

Relation Between Mental Rotation and Line Angle Judgment Parameters, Across Nations

Across nations, men's and women's mean performance on the mental rotation task correlated substantially with men's

Table 1 Correlations between national indices of gender equality and economic development and national mental rotation parameters (men's means, women's means, and standardized sex differences)

	Men's mean mental rotation	Women's mean mental rotation	Sex differences (*d*s)	Sex differences (*d*s), controlling for education and age variables
UN gender development	.83*** (53)	.70*** (53)	.47*** (53)	.42** (53)
UN gender empowerment	.77*** (47)	.72*** (47)	.29* (47)	.11 (47)
Per capita income	.65*** (52)	.64*** (52)	.22 (52)	.08 (52)
Life expectancy	.58*** (53)	.44** (53)	.40** (53)	.33* (53)

Note: * $p < .05$, ** $p < .01$, *** $p < .001$. Numbers in parentheses are sample sizes. Control variables in partial correlations were: percent of men with greater than high school education, percent of women with greater than high school education, ratio of percent of men to percent of women with greater than high school education; mean age of men, mean age of women, ratio of men's mean age to women's mean age

Table 2 Correlations between national indices of gender equality and economic development and national line angle judgment parameters (men's means, women's means, and standardized sex differences)

	Men's mean line angle judgment	Women's mean line angle judgment	Sex differences (*d*s)	Sex differences (*d*s), controlling for education and age variables
UN gender development	.63*** (53)	.37** (53)	.41** (53)	.47** (53)
UN gender empowerment	.48** (47)	.29* (47)	.33* (47)	.31* (47)
Per capita income	.51*** (52)	.30* (52)	.34* (52)	.42** (52)
Life expectancy	.54*** (53)	.12 (53)	.57*** (53)	.68*** (53)

Note: * $p < .05$, ** $p < .01$, *** $p < .001$. Numbers in parentheses are sample sizes. Control variables in partial correlations were: percent of men with greater than high school education, percent of women with greater than high school education, ratio of percent of men to percent of women with greater than high school education; mean age of men, mean age of women, ratio of men's mean age to women's mean age

and women's mean performance on the line angle judgment task (correlations ranged from .62 to .72; all significant at $p < .001$). Thus, mean performance on the two tasks covaried, across nations. In contrast, the magnitude of sex differences in mental rotation and sex differences in line-angle judgment performance were not significantly correlated across nations, $r(52) = .23$, $p = .105$. Despite the lack of significant relationship between sex differences in mental rotation and line angle judgment performance, across nations, the cross-nation patterns in sex differences shown in Tables 1 and 2 were similar—i.e., sex differences in both mental rotation and line angle judgment performance tended to be larger in gender egalitarian and economically developed nations than in less egalitarian and less developed nations.

Discussion

The current findings extend recent research on the cross-cultural consistency of sex differences to two cognitive domains: mental rotation performance and line angle judgment performance. Analysis of data from the BBC Internet study showed that universally, across 53 nations, men's mean performance exceeded women's mean performance on these two visuospatial tasks. Furthermore, the magnitude of the sex differences tended to be positively associated with nations' gender equality and economic development, a finding that runs counter to the predictions of social role and gender socialization theories. This pattern of results remained after controlling for variations in mean age and education levels across national samples.

These results were inconsistent with hypotheses derived from stereotype threat theory, when augmented by the assumption that gender stereotypes about sex differences in cognitive abilities are likely to be stronger in gender non-egalitarian than gender egalitarian societies. In contrast, the current results were consistent with hypotheses derived from stereotype threat theory, when augmented by the assumptions that (1) information about scientific research on sex differences in cognitive performance may be more widely disseminated in economically developed, gender egalitarian countries and (2) women in economically developed, gender egalitarian countries may have a greater desire to perform well on stereotypically male-favored tasks than do women in less developed, gender non-egalitarian countries. Adequate future testing of the application of stereotype threat theory to cross-cultural variations in sex differences in cognitive performance will require that researchers assess, across nations, a number of factors—e.g., the strength of relevant stereotypes, the level of men's and women's knowledge about scientific research on sex differences, and the importance that men and women assign to performing well in various cognitive domains—and then examine the correlation of

these factors with sex differences in performance across nations.

As noted earlier, attributional and social comparison theories that attempt to explain how psychological sex differences vary across countries seem to apply more readily to psychological traits that entail self-ratings (e.g., self-reported personality, emotions, values) than to cognitive traits. Thus, the current findings—that sex differences in mental rotation and line angle judgment performance showed cross-cultural patterns similar to those found in research on other traits—provide new information about possible causes of cross-cultural variations in cognitive sex differences.

The pattern of results reported here was consistent with the predictions of evolutionary theories that hypothesize an interaction between evolved sex-linked dispositions and environmental affordances (Schmitt et al., 2008). Specifically, the current results showed that sex differences tended to be larger in gender egalitarian, economically advanced nations, which were hypothesized to facilitate optimal development in both men and women, and smaller in gender non-egalitarian and less developed nations, which were hypothesized to limit both men's and women's development. One prediction that followed from evolutionary theories, but ran counter to the predictions of social role and stereotype threat theories, was that national variations in gender roles and economic development may impact men's more than women's performance, assuming that males are more vulnerable than females to environmental challenges (see Halpern et al., 2007; Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005). Although the current data do not offer conclusive evidence on this point, correlations between national indices and men's national mean performance were consistently larger than corresponding correlations for women (see Tables 1, 2).

Several limitations to the BBC data are worth noting. First, the BBC participants did not comprise a random sample. Because the BBC survey was implemented via the Internet, it tended to attract participants who were young, educated, and computer savvy (see Reimers, 2007). At the same time, the national samples assessed by the BBC survey were often larger and more diverse, in terms of participants' age and geographic locale, than the samples assessed in many recent cross-cultural studies of sex differences and, unlike much recent cross-cultural research on sex differences, the BBC sample included many non-college-student participants.

The BBC survey was implemented in English, which may have affected the responses of participants from non-English-speaking counties. Although instructions for the mental rotation and line angle judgment tasks were in English, the tests themselves were "nonverbal," and thus it could be argued that performance on these tests was less affected by English fluency than other measures in the BBC survey. Finally, the mental rotation test used in the BBC survey was shorter than standard paper-and-pencil mental rotation tests, and participants' performance on the mental rotation and line angle judgment tasks in the BBC survey may have been subject to more sources of error variance than performance under more standardized laboratory settings. Indeed, mental rotation and line angle judgment tasks administered in controlled settings often show larger mean sex differences than those reported here (Collaer et al., 2007; Peters et al., 2007). Thus, the current results, if anything, may underestimate the true strength of associations.

Finally, it is important to note that men's and women's mean levels of performance on the two visuospatial tasks were linked to social, cultural, and environmental factors. Although associations were stronger for mental rotation performance than for line angle judgment performance, measures of gender equality and measures of economic development tended to be significantly associated, across nations, with both kinds of visuospatial performance, and these associations were present for both men and women. We can only speculate why visuospatial performance tended to be positively associated with gender equality and economic development, across nations. Contributing factors may have included national differences in health care and nutrition, education, exposure to computers and video games, and architectural environments. Further research is warranted that investigates why people in different nations vary systematically in their visuospatial performance.

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