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# Sex differences in the relation between math performance, spatial skills, and attitudes

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ABSTRACT

Sex differences have been previously found in cognitive and affective predictors of math achievement, including spatial skills and math attitudes. It is important to determine whether there are sex differences not only in the predictors themselves, but also in the nature of their relation to math achievement. The present paper examined spatial skills and math attitudes as predictors of curriculum-based measures of math performance in middle-school students, specifically comparing the patterns of these predictive relations for boys and girls. The results of the current study showed that, despite similar levels of math performance for boys and girls, the significance of particular predictors varied as a function of sex. Specifically, spatial skills predicted math performance in boys, but not in girls. We suggest that sex differences in spatial reasoning in conjunction with the differential involvement of spatial reasoning in math problem solving may lead to later sex differences in math outcomes.



There is concern that the United States will be unable to maintain its position as a leader in science and technology due to a shortage of highly-skilled mathematicians and scientists (National Science Board, 2010). The situation is further complicated by a persisting imbalance in the workforce, whereby women are significantly underrepresented in STEM careers (Science, Technology, Engineering and Mathematics). It has been suggested that this disparity has its origins at earlier educational stages (Muller, Stage, & Kinzie, 2001; Sanchez & Wiley, 2010). Robust sex differences in cognitive and affective predictors of math performance are found starting in middle school (Meece, Wigfield, & Eccles, 1990; Voyer, Voyer, & Bryden, 1995) and these differences in predictors may lead to later sex differences in math achievement and STEM careers. To address the need for skilled mathematicians, it is important to understand how to maximize students' achievement potential. This, in turn, would require a better understanding of how specific cognitive and affective processes may be related to performance in boys and girls. In the present paper, we investigated whether the nature of the relations between predictor variables and math performance differed by sex.

## Spatial skills and math attitudes as predictors of math performance

In considering various cognitive and affective factors related to math achievement, we have chosen to focus here on spatial skills and math attitudes, which have been implicated in math performance and show sex differences. Among spatial skills, mental rotation ability in particular has been identified as a powerful predictor of students' math test scores (e.g., Casey, Nuttall, Pezaris, & Benbow, 1995; Reuhkala, 2001). This relation has been documented for middle- and high-school students as well as college undergraduates (Battista, 1990; Casey et al., 1995; Delgado & Prieta, 2004; Friedman, 1995; Reuhkala, 2001; Voyer, 1996; Voyer & Sullivan, 2003). Among the affective factors, math attitudes – in particular, confidence and anxiety – have been shown to relate to math achievement (Dwinell & Higbee, 1991; Eccles & Jacobs, 1986; Ma, 1999; Ma & Kishor, 1997). In discussing both spatial ability and math attitudes as predictors of math performance, researchers often emphasize sex differences in these constructs, and the need to understand their role in the development of later sex differences in academic achievement and career choices (e.g., Eccles & Jacobs, 1986; Linn & Petersen, 1985).

## Sex differences in predictors of math performance

### *Sex differences in spatial skills*

Among spatial measures, the largest sex difference is found on mental rotation tasks, which require the ability to hold images in one's mind while mentally manipulating them (Vandenberg & Kuse, 1978). On these tasks, males tend to outperform females in both accuracy and speed (e.g., Masters & Sanders, 1993). Recent studies suggest that sex differences on certain tasks involving mental rotation emerge in young children; however, the differences become more robust starting in middle-school and further increase through the college years (Geiser, Lehmann, & Eid, 2008; Levine, Huttenlocher, Taylor, & Langrock, 1999; Voyer et al., 1995). This increase can be seen in the changes in effect sizes (Cohen's $d$) —from 0.13 for children under 13,

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to 0.45 for children 13–18, and 0.66 for students over 18 (Voyer et al., 1995). Across the age groups, sex differences in mental rotation are particularly pronounced on tasks that involve 3-D stimuli, such as the Vandenberg Mental Rotation Test (Linn & Petersen, 1985; Nordvik & Amponsah, 1998; Voyer et al., 1995).

### *Sex differences in math attitudes*

Numerous studies have found that females are less confident than males in their mathematical abilities (Catsambis, 1994; Else-Quest, Hyde, & Linn, 2010; Herbert & Stipek, 2005; Hyde, Fennema, Ryan, Frost, & Hopp, 1990; Meece et al., 1990; Sherman, 1980). This relative lack of confidence has been documented even in samples of students in which girls obtain higher math grades than boys (e.g., Pomerantz, Altermatt, & Saxon, 2002). The differences in math confidence are mirrored by sex differences in math anxiety, with most investigators reporting higher anxiety in females, compared to males (Eccles & Jacobs, 1986; Else-Quest et al., 2010; Ma & Cartwright, 2003; Meece et al., 1990; Tocci & Engelhard, 1991). For both math confidence and anxiety, the developmental trajectory shows an increase in sex differences from middle to high school and further into the college years (Hyde et al., 1990).

## Exploring the nature of sex difference in math performance

Whereas evidence concerning sex differences in spatial skills and math attitudes has been quite consistent, there is less consistency with respect to findings on sex differences in math performance. In fact, many studies reveal no sex differences in math achievement, whereas others point to either female or male advantage. Variability in the existing findings can be attributed, in large part, to variability in the nature of the assessment instrument used (Gibbs, 2010).

### *Evidence from non-curricular assessments*

Much of the extant research investigating sex differences in mathematics has utilized non-curricular measures of math performance. In contrast to curriculum-based tests, these measures are relatively independent of the particular curricular standards formulated by individual states or local school districts; rather, they aim to assess students' ability to apply key mathematical concepts to problem solving. Examples of non-curricular tests include SAT-Math, Trends in International Mathematics and Science Study (TIMSS), and the Program for International Student Assessment (PISA), which are designed to evaluate a range of skills viewed as essential for the mastery of the mathematical domain (Liu & Wilson, 2009).

Most studies utilizing non-curricular measures of math achievement indicate that sex differences are relatively small and more pronounced in older students (Gallagher & Kaufman, 2005; Halpern, 2000; Hyde, Fennema, & Lamon, 1990). A recent meta-analysis reported no sex differences in elementary and middle school students and a small but significant male advantage in high school and college samples (Lindberg, Hyde, Petersen, & Linn, 2010). In addition to grade level, the pattern of sex differences varies as a function of item type (Gibbs, 2010). Detailed item analyses indicate that girls do better on conventional problems that can be solved using procedures taught in the classroom and boys do better in complex problem solving, including unconventional problems that require extending learned concepts to novel contexts (Gallagher et al., 2000; Gallagher & De Lisi, 1994; Hyde et al., 1990; Lindberg et al., 2010).

### *Evidence from curriculum-based assessments*

The research on non-curricular assessments presented above indicates that the extent and even direction of sex differences in math performance depend on the skills and knowledge required by the test items. Based on this research, one could expect that curriculum-based assessments, which evaluate skills and procedures taught in the classroom, will not reveal a male advantage. Indeed, when looking at math grades, which serve as indicators of students' mastery of classroom-taught material, researchers often find that girls outperform boys (Catsambis, 1994; Ding, Song, & Richardson, 2006; Downey & Vogt Yuan, 2005; Pomerantz et al., 2002; Willingham & Cole, 1997). Girls' advantage in math grades may be related both to the fact that they are likely to do better on classroom assessments tied to the curriculum and that they are more likely to excel in other areas considered by teachers when assigning course grades (e.g., effort, homework completion).

In addition to grades, students' learning of the math content presented in their curriculum can be assessed through standardized tests that are based on the specific curricular framework used for instruction. Such curriculum-based tests have become increasingly important with the passing of the No Child Left Behind Act (NCLB, 2002), which mandates that all states test students' mastery of state-established academic standards (Ryan, Ryan, Arbuthnot, & Samuels, 2007). The items included in curriculum-based assessments tap the same major strands of mathematical knowledge as the items on non-curricular tests, but the nature of problems often differs markedly across the two types of tests. A recent study of state math assessments indicated that items tapping students' extended and strategic thinking about mathematical concepts were virtually absent from these assessments (Hyde, Lindberg, Linn, Ellis, & Williams, 2008). Most of the items required recall of information and direct application of learned algorithms. Because boys tend to do better on complex problem solving, a male advantage would not be expected on the type of assessment that does not tap into their strengths. Indeed, an examination of test results from ten U.S. states indicates that there is no sex difference on the math portion of these tests (Hyde et al., 2008).

## Sex differences in the relations between predictive factors and math achievement

As shown in the analysis of current research, sex differences in math achievement are virtually non-existent on curriculum-based tests through high school and on non-curricular tests through middle school. At the same time, a male advantage is continuously found in complex problem solving in high school students. This may have significant implications for STEM-related careers, which often require integrating concepts in novel ways and discovering creative approaches to complex problems. Thus, despite the relatively small size of the sex difference observed in high school, it is critical to understand its contributing factors and explore potential precursors of this sex difference at the earlier developmental stages, in particular, in middle school (Muller et al., 2001; Sanchez & Wiley, 2010).

One way of approaching this issue is by focusing on the predictors of math performance and examining potential sex differences in how these predictors are related to math outcomes. There are limited and inconsistent findings on whether the relation of cognitive and affective predictors to math achievement differs by sex. A recent study of kindergarten students found that spatial skills (including mental rotation) were related to math performance for boys but not for girls (Klein, Adi-Japha, & Hakak-Beizri, 2010). In contrast, evidence obtained in college-age students suggests that spatial skills are a stronger predictor of SAT-Math performance for girls than boys (Casey et al., 1995). Both studies utilized non-curricular assessments, although the kindergarten study tested the mastery of basic numeric and computational skills whereas the college study tested the mastery of a range of skills, including complex problem solving. Thus, there may be a difference in how spatial skills predict math achievement at different ages and for different types of math assessments. So far, there is no work to help us understand the nature of this relationship in middle school years, the time when sex differences in mental rotation become particularly strong and robust. Further, there is no