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Reducing the sex difference in math anxiety: The role of spatial processing ability

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A B S T R A C T

Decades of research have demonstrated that women experience higher rates of math anxiety – that is, negative affect when performing tasks involving numerical and mathematical skill – than men. Researchers have largely attributed this sex difference in math anxiety to factors such as social stereotypes and propensity to report anxiety. Here we provide the first evidence that the sex difference in math anxiety may be due in part to sex differences in *spatial processing ability*. In Study 1, undergraduate students completed questionnaires assessing their level of math anxiety and their aptitude and preference for processing spatial configurations and schematic images. The results support the hypothesis that the relation between sex and math anxiety is mediated by spatial processing ability. In Study 2, we replicate these results with a more diverse sample of adults. Implications for the prevention and remediation of math anxiety and math anxiety-related achievement deficits are discussed.

Strong mathematical abilities are critical for success in many facets of life, including employability and wages. For example, a deficit in basic mathematical abilities has a greater negative impact on employment opportunities than reading difficulties (Bynner & Parsons, 1997), and mathematical competence is even more predictive of earning potential than people's level of literacy, years of schooling, and intelligence (Bishop, 1989; Boissiere, Knight, & Sabot, 1985; Rivera-Batiz, 1992). It is thus no surprise that, in industrialized societies, quantitative competencies are at an economic premium (Paglin & Rufolo, 1990). For instance, Paglin and Rufolo (1990) report a direct relation between the quantitative demands of various careers and their associated wages such that the more math-intensive the occupation, the higher the entry-level and subsequent wages. The development and preservation of numerical and mathematical competencies are thus of crucial importance for individuals within these societies and for the society as a whole (Geary, 2000). Regrettably, women are sorely underrepresented in STEM fields (science, technology, engineering, and math), which place heavy demands on mathematical competencies (Chipman, Krantz, & Silver, 1992). One factor that has been implicated in women's avoidance of math-related careers is math anxiety (Chipman et al., 1992).

Math anxiety is a condition in which individuals experience negative affect when engaging in tasks demanding numerical and mathematical skills (Richardson & Woolfolk, 1980). Across a number of studies, individuals high in math anxiety have been shown to perform more poorly than their low math anxious peers on a range of numerical and mathematical tasks, from counting objects and comparing numbers (Maloney, Ansari, & Fugelsang, 2011; Maloney, Risko, Ansari, & Fugelsang, 2010) to more complex arithmetic problems involving carrying (Ashcraft & Faust, 1994). High math anxious individuals are less likely than their low math anxious peers to take elective math classes and they tend to perform more poorly in the classes that they do take (Hembree, 1990). Importantly, math anxiety is more likely to affect women than men (Hembree, 1990). To date, there has been no definitive answer to the question of why women are more likely to be math anxious than men. However, a few theories have been put forth: for example, Ashcraft and colleagues speculate that the sex difference in math anxiety may occur because women are more likely to report anxiety (e.g., Ashcraft, 2002). Alternatively, Beilock, Rydell, and McConnell (2007) suggest that the sex difference is the result of the social stereotype that women are not good at math. Both a higher propensity to report anxiety and social stereotypes likely play some role in the fact that women report being more math anxious than men. That said, given the evidence suggesting that math anxiety may develop as a result of basic cognitive factors (e.g., poor 'number sense', Maloney et al., 2010, 2011), it is possible that cognitive factors may also play a role in the sex difference in math anxiety.

One of the most commonly reported sex differences in cognitive psychology is in certain types of spatial processing ability. Spatial processing ability refers to skill in representing and transforming symbolic, non-linguistic information (Gardner, 1983). It has long been established that men tend to outperform women on some specific measures of spatial processing ability, such as mental rotation ability

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(e.g., Linn & Petersen, 1986). The link between spatial processing ability and math abilities has been widely studied (e.g., Ackerman & Dykman, 1995). Although some of the evidence is conflicting, there does appear to be a connection between poor spatial skills and low math achievement. For example, Rotzer et al. (2009) demonstrated that children with Developmental Dyscalculia present with poor spatial processing ability and impaired performance in mathematics. Specifically, Rotzer et al. (2009) demonstrated that children with Developmental Dyscalculia presented with both lower performance on a spatial working memory task (the Corsi Block Tapping task) and decreased neural activation in the brain regions associated with spatial working memory (i.e., right intraparietal sulcus, right insula and right inferior frontal lobe) relative to normal achieving children. Rotzer et al. (2009) argued that poor spatial working memory processes may inhibit the formation of spatial-number representations (i.e., the mental number line) in addition to the storage and retrieval of arithmetic facts which form the basis for complex math. Interestingly, research by Miller and Bichsel (2004) has also shown a relation between math anxiety and performance on another spatial working memory task, the paper folding task. In fact, we believe that poor spatial processing ability may be a contributing factor in the development of math anxiety. Specifically, students who start out with poor spatial processing abilities may be more likely to struggle in math, resulting in negative experiences with math. As a result of their difficulty and negative experiences, these students will be more likely to develop math anxiety. Against this background, we tested the hypothesis that the relation between sex and math anxiety is mediated by spatial processing ability.

1. Study 1

1.1. Method

1.1.1. Participants

One hundred and eighteen (80 female, 38 male) undergraduate students from the University of Waterloo participated in the study in exchange for credit in a psychology class.

1.1.2. Materials

Abbreviated Math Anxiety Questionnaire (AMAS; Hopko, Mahadevan, Bare, & Hunt, 2003). The AMAS is a 9-item questionnaire measuring math anxiety. Total scores range from 9 (not at all math anxious) to 45 (very math anxious). The AMAS has excellent internal consistency ($\alpha = .90$) and two-week test retest reliability ($r = .85$; Hopko et al., 2003).

Object Spatial Imagery Questionnaire (OSIQ; Blajenkova, Kozhevnikov, & Motes, 2006). The OSIQ is a 30-item questionnaire consisting of two 15-item scales, a Spatial scale and an Object scale. The Spatial scale is a measure of individuals' aptitude and preference for processing and imaging schematic images and the spatial relations between objects. Scores on the spatial scale correlate with performance on spatial tasks such as the mental rotation task (Blajenkova et al., 2006). Cronbach's alpha for the spatial scale in the validation study was .83. The Object scale is a measure of individuals' aptitude and preference for imaging colorful, picture-like images. Cronbach's alpha for the Object scale in the validation study was .79. Both scales have an excellent one-week test–retest reliability, ($r = .81$ for the spatial scale and $r = .95$ for the object scale; Blajenkova et al., 2006). The spatial and object subscales of the OSIQ are typically administered together. Thus, although we had no theoretical grounds on which to include the Object subscale, we nonetheless decided to include it for exploratory purposes.

1.1.3. Procedure

Participants completed both the OSIQ and the AMAS online. They also identified their biological sex.

1.2. Results

Thirteen participants skipped one or two items on one or more questionnaires, resulting in 21 missing item scores in the full data set (less than 0.5% of total data). Missing scores were replaced by participants' scale means. Individuals' total scores were computed for the AMAS; individuals' mean scores were computed for the OSIQ Spatial scale and the OSIQ Object scale, consistent with how these measures are typically scored in the literature. Mean scores by sex are presented in Table 1.

We tested the hypothesis that the relation between sex and math anxiety is mediated by spatial processing ability. Structural equation modeling (SEM) using SPSS AMOS was used to test the meditation model (Fig. 1). First, sex was dummy-coded such that males were coded as 1 and females as 0. Then, the standardized path coefficients (Fig. 1) were computed. For the mediation analysis, the strength and significance of indirect effects were estimated using a bootstrap sampling method (Shrout & Bolger, 2002; recommended by MacKinnon, Lockwood, & Williams, 2004). As expected, sex predicted spatial processing ability ($\beta = .41$, $SE = .068$, $p < .01$). In turn, spatial processing ability was negatively associated with math anxiety ($\beta = .45$, $SE = .08$, $p < .01$). The indirect effect between sex and math anxiety (through spatial processing ability) based on 5000 bootstrap samples was significant ($\beta = -.19$, $SE = .048$, $p < .01$, 95% confidence interval from $-.10$ to $-.29$). Thus, the present data are consistent with a mediation model and indicate that the sex difference in math anxiety can be explained, at least in part, by sex differences in spatial processing ability.

Interestingly, object imagery ability was also significantly correlated with sex ($r = -.22$, $p < .05$; females report higher object imagery ability than men) and with math anxiety scores ($r = .28$, $p < .01$) in the current sample. Object imagery ability was not correlated with spatial processing ability ($r = -.09$, $p = .32$).

1.3. Discussion

The data from Study 1 are consistent with a mediation model (see Fig. 1) whereby the effect of sex on math anxiety is mediated by spatial processing ability. Because this is a novel finding and our sample was comprised of university students taking a psychology course, we were also interested in exploring the relation between these variables in a more diverse population. Study 2 addresses this issue.

2. Study 2

2.1. Method

2.1.1. Participants

Two hundred and forty nine adults (151 female, 98 male) were recruited online using Amazon's Mechanical Turk (www.MTurk.

Table 1
Descriptive statistics for Studies 1 and 2.

Study/ measures	Males		Females	
	Mean score	Standard deviation	Mean score	Standard deviation
Study 1				
Age	20.74	3.53	21.09	5.19
AMAS	16.87	6.46	21.14	6.99
OSIQ object	3.15	.67	3.49	.69
OSIQ spatial	3.16	.42	2.69	.52
Study 2				
Age	34.34	12.00	35.04	12.48
AMAS	20.47	7.90	22.09	7.89
OSIQ object	3.42	.63	3.51	.62
OSIQ spatial	3.08	.63	2.56	.63

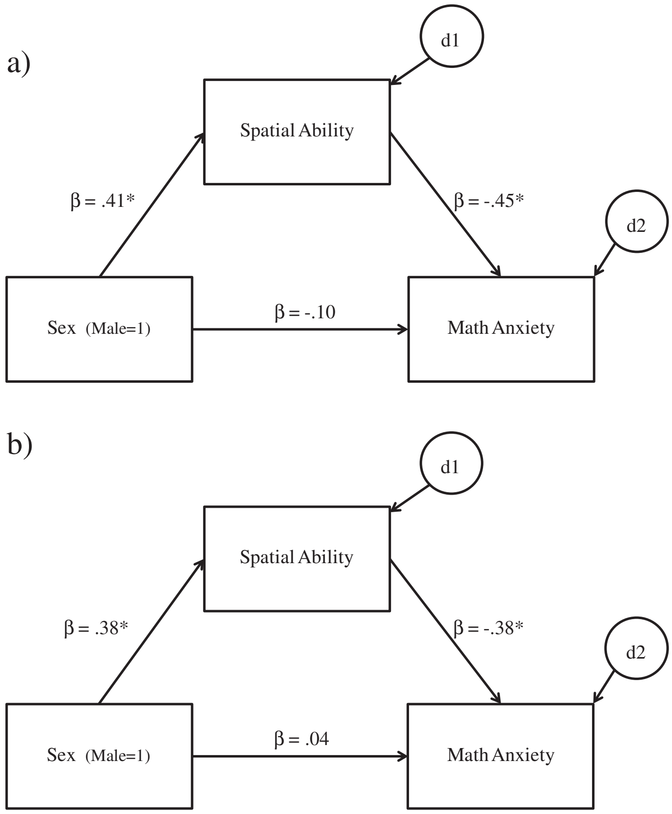

Fig. 1. Results for Study 1 with an undergraduate sample (a, top image) and Study 2 with a more diverse sample (b, bottom image). The figure shows mediation of the effect of sex on math anxiety through spatial ability. Asterisks indicate the significance of the coefficients (*$p<.05$).

com; see Buhrmester, Kwang, & Gosling, 2011, for a discussion of MTurk and psychological research). The participants ranged in age from 18 to 78 and received a small monetary award in return for their participation.

2.1.2. Measures and procedures

All measures and procedures were the same as Study 1.

2.2. Results

Thirty-seven participants skipped one to three items on one or more questionnaires, resulting in 71 missing item scores in the full data set (less than 0.8% of total data). Missing scores were replaced by participants' scale means. Again, individuals' total scores were computed for the AMAS and mean scores were computed for the OSIQ Spatial and Object scales (Table 1). Mean scores by sex are reported in Table 1.

As in Study 1, structural equation modeling using SPSS AMOS was used to test the meditation model (Fig. 1). The strength and significance of indirect effects were again estimated using a bootstrap sampling method. As expected, sex predicted spatial processing ability ($\beta=.38$, $SE=.054$, $p<.01$). In turn, spatial processing ability was negatively associated with math anxiety ($\beta=-.38$, $SE=.061$, $p<.01$). The indirect effect between sex and math anxiety (through spatial processing ability) based on 5000 bootstrap samples was significant, $\beta=-.14$, $SE=.030$, $p<.01$, 95% confidence interval from $-.09$ to $-.21$. Thus, the present data are also consistent with the mediation model.

In this sample, object imagery ability was not significantly correlated with sex ($r=-.07$, $p=.30$) or math anxiety ($r=-.06$, $p=.38$).

2.3. Discussion

Study 2 also tested the hypothesis that that the relation between sex and math anxiety is mediated by spatial processing ability, this time with a more diverse sample of participants. Participants in this sample ranged in age from 18 to 78 and had a variety of education levels. The data from our second sample were also consistent with a mediation model (see Fig. 1) whereby the effect of sex on math anxiety is mediated by spatial processing ability. We discuss the implications of this finding below.

3. General discussion

The results of the present investigation demonstrate that math anxiety is negatively related to spatial processing ability. Importantly, they also demonstrate that the commonly-observed sex difference in math anxiety is not due simply to social stereotypes or to women's willingness to report anxiety. In fact, the sex difference in math anxiety is mediated by spatial processing ability. In other words, women may be more math anxious than men on average because women are worse at spatial processing than men on average.

The results of the present investigation are important for our understanding of the sex difference in math anxiety as they suggest an interpretation that runs counter to the way in which this sex difference is typically discussed. Specifically, to date psychologists have attributed the sex difference in math anxiety to social factors such as the possibility that women are more likely to disclose anxiety (Ashcraft, 2002) and to stereotypes about women's mathematical abilities (Beilock et al., 2007). While these mechanisms likely do contribute, the present data highlight the strong relation between sex differences in math anxiety and sex differences in spatial processing ability.

While the mechanism underlying sex differences in spatial processing are not completely understood, one theory is that sex differences in spatial processing ability result from varying levels of androgens across the sexes. Multiple studies have demonstrated that higher levels of testosterone are associated with better performance on measures of spatial processing ability (e.g., Gouchie & Kimura, 1991; Moffat & Hampson, 1996) and that testosterone administration enhances visual–spatial performance (e.g., Cherrier et al., 2001, 2007; Janowsky, Chavez, & Orwoll, 2000; Janowsky, Oviatt, & Orwoll, 1994). In the context of this theory, the sex effect in math anxiety is related to differences in levels of testosterone between high and low math anxious individuals. This claim, however, remains to be empirically demonstrated.

The results of the present investigation are correlational and, as such, one cannot draw conclusions regarding the direction of causality. For example, it is possible that math anxiety causes poor spatial processing ability rather than the reverse. As noted earlier, math anxiety leads individuals to avoid math (Hembree, 1990). If experience with math leads to improved spatial skills, then the tendency for high math anxious individuals to avoid math could lead to difficulties with spatial processing. However, we are unaware of any evidence for such a mechanism.

A more likely explanation is that poor spatial processing ability precedes math anxiety. Spatial skills emerge early in development and sex differences in mental rotation ability are apparent in infants as young as 5 months (Moore & Johnson, 2008). Furthermore, researchers have argued that individuals' proficiency in spatial processing and spatial reasoning tends to remain reasonably stable after early childhood (e.g., by early elementary school, see Mortensen, Andresen, Kruuse, Sanders, & Reinisch, 2003). As such, it is possible that poor spatial processing ability acts as an obstacle to achievement in mathematics (e.g., Geary, 2004; Rotzer et al., 2009). As a result, children with poor spatial processing ability would likely experience more negative encounters with math than their spatially inclined peers. These children could, as a result, develop math anxiety. This anxiety would in turn compromise online working memory capacity during math tasks (Ashcraft & Kirk, 2001) and lead individuals to avoid situations that require mathematical processing. These individuals are then less likely to take advantage of situations that allow them to hone their math skills. Of course, given that women, on average, have poorer spatial skills than men (at least measured by some tasks), women should also be more likely to develop math anxiety. By this account, in adults, math performance should also mediate the relation between sex and math anxiety. However, as we did not measure math ability in the present study, this remains an empirical question.

Given that the sex difference in math anxiety has been implicated in the underrepresentation of women in STEM fields (Chipman et al., 1992), and given that mathematical competence is critical for societies as a whole (Geary, 2000), then understanding the cause of this sex difference in math anxiety may prove to be an extremely valuable tool in the fight against underachievement in mathematics. Certainly any remediation programs aimed at combating the issue of the underrepresentation of women in STEM fields should take into consideration the present finding. Specifically, spatial training, such as playing action video games (Feng, Spence, & Pratt, 2007), has been shown to reduce the sex differences in spatial processing in only a few short training sessions. Spatial processing training has been shown to improve spatial skills (Lohman & Nichols, 1990; Sorby, 2009), and, importantly, spatial skills training can even increase performance in academic subject areas. For example, Sorby (2009) found that spatial training was associated with higher grades in subsequent calculus and physics courses (see also Blasko & Holliday-Darr, 2010). Given these promising results, the training of spatial skills for both men and women with low spatial processing ability may represent an exciting and effective intervention for the prevention and remediation of math anxiety and math performance.

The final issue to address here is the positive correlation between math anxiety and object imagery ability in Study 1. These results indicate that high math anxious university students perceive themselves as being particularly skilled at conjuring up vivid mental images. Interestingly, these data are the first to highlight an area in which math anxious individuals report *higher aptitude* than their non-math anxious peers. While there is no direct evidence from the literature to suggest why object imagery is related to math anxiety, research examining imagery skills in math problem solving may serve to shed some light. Specifically, Van Garderen and Montague (2003) demonstrated that, when trying to solve written math problems, children who use pictorial imagery (imagery that encodes the persons, places, or things described in the problem) perform more poorly on those problems than children who use schematic (i.e., spatial) imagery. We did not ask participants which type of imagery they are most likely to use when solving written math problems. However, if the students who are particularly good at conjuring up detailed images of people, places, and things (i.e., the good object imagers) are also more likely to use this type of imagery when solving math problems, and this type of imagery is associated with poor performance in math, then this may explain why math anxiety appears to be related to object imagery in certain samples.

4. Conclusion

In the present investigation, we have demonstrated evidence that the relation between sex and math anxiety is mediated by spatial processing ability. The results of this study not only help explain why women are more math anxious than men, but also provide insights into potential training techniques which may serve to reduce the sex gap in STEM fields.

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