Mediation Relationships Among Gender, Spatial Ability, Math Anxiety, and Math Achievement

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REVIEW ARTICLE

Mediation Relationships Among Gender, Spatial Ability, Math Anxiety, and Math Achievement

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Abstract
In this review, findings from studies investigating gender differences in spatial ability, math anxiety, and math achievement, the relationship between spatial ability and math anxiety, between spatial ability and math achievement, and between math anxiety and math achievement are synthesized. As a result of this synthesis, a sequential mediation model that allows simultaneous testing of two mediational relationships has been derived. Within this model, paths from gender to spatial ability, from spatial ability to math anxiety, and from math anxiety to math achievement are more strongly supported by prior studies than the paths from gender to math anxiety, from gender to math achievement, and from math achievement to math anxiety.

Keywords Gender · Spatial ability · Math anxiety · Math achievement · Mediation

Introduction

A convergence of evidence from brain research, intervention studies, and correlational studies points to the close relationship between spatial ability and numerical cognition (Cheng and Mix 2014; Cherney et al. 2014; Dehaene et al. 2003; Newcombe 2017; Verdine et al. 2017). Specifically, spatial ability has been shown to be a positive predictor of math achievement (Gunderson et al. 2012; Uttal et al. 2013) and is considered a foundational skill for higher order mathematical thinking (Maloney 2016). Spatial ability has also been shown to be inversely related to math anxiety (Ferguson et al. 2015). Math anxiety, in turn, has been shown to be inversely related to math achievement (Foley et al. 2017). There is strong evidence for both gender differences in spatial ability (Voyer et al. 1995) and math anxiety (Else-Quest et al. 2010). Findings on gender differences in math achievement are not as clear-cut, with older studies and studies that focused on the US populations revealing more gender differences in

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favor of males, and more recent studies and studies that focused on international populations showing fewer or no gender differences. The main objectives of this review are as follows: (1) to illustrate the negative predictive relationship between spatial ability and math anxiety; (2) to illustrate the inverse relationship between math anxiety and math achievement; (3) to discuss these relationships in the context of gender differences literature; (4) to synthesize the literature concerning gender, spatial ability, math anxiety, and math achievement; (5) to evaluate the quality of the studies that point to the more probable mediation relationships deduced from the literature. The review concludes with a model involving gender, spatial ability, math anxiety, and math achievement, allowing simultaneous testing of two mediation relationships. Through deductive reasoning, this model is derived from empirical studies that focused on subsets of variables included in the proposed model. The hypothesized mediation relationships featured in this model hold promise for future empirical testing and are of theoretical and practical interests.

Spatial Ability

Spatial ability refers to a constellation of related skills that involves representing and transforming symbolic, nonlinguistic information (Gardner 2011). Although there is no consensus regarding the best way to classify garden varieties of spatial abilities, the distinction between small-scale (e.g., mental rotation) and large-scale (e.g., perspective-taking) spatial abilities is widely recognized (see Hegarty et al. 2006; Hegarty and Waller 2004). Large-scale spatial ability refers to the ability to understand different perspectives when viewing a large-scale spatial layout, whereas small-scale spatial ability refers to the ability to mentally manipulate 2D or 3D representations (Wang et al. 2014). The two types of spatial abilities are partially dissociated (Hegarty et al. 2006), and each is supported by a distinct neurological underpinning (see Wolbers and Hegarty 2010; Zacks 2008). Because small-scale spatial ability has greater implications to the type of thinking involved in mathematical reasoning, this study will focus on small-scale spatial ability. Small-scale spatial ability can be further divided into three categories (see Linn and Petersen 1985), among which mental rotation is most well-researched and provides the strongest evidence for gender differences.

1.11. Gender Differences in Spatial Ability

Gender differences in spatial ability are well documented (see Linn and Petersen 1985; Voyer et al. 1995; Voyer et al. 2017). Neuroimaging research revealed that different neural networks may be involved when males and females perform three-dimensional mental transformation (Jordan et al. 2002), with women exhibiting significant bilateral activations in the intraparietal sulcus, the superior and inferior parietal lobule, the inferior temporal gyrus, and the premotor areas and men exhibiting significant activation in the right parieto-occipital sulcus, the left intraparietal sulcus, and the left superior parietal lobule (Jordan et al. 2002). The gender effect favoring males is strongest on mental rotation tests. A recent meta-analysis also revealed a male advantage in visuospatial working memory (VSWM) as measured by complex span tasks, although the effect is weaker than that of mental rotation (see Voyer et al. 2017). Overall, there is strong evidence that on average, males outperform females on spatial ability tests, with mental rotation tests showing the strongest gender effect favoring males.

1.2. Math Anxiety

Math anxiety refers to a negative emotional response some individuals experience when they work with numbers or are in math-related situations (Suárez-Pellicioni et al. 2016). The negative emotional state is sufficient to disrupt actual performance on math tasks. Although not formally recognized as a type of phobia, math anxiety resembles a phobia in many ways (Ashcraft and Ridley 2005). There is physiological evidence (e.g., increases in heart rate) that suggests math anxiety is very specific to math-related situations (see Faust 1992). Although at a behavioral level, existing evidence suggests that math anxiety is a distinct form of anxiety from other forms of anxieties (e.g., PTSD, social phobia, specific phobias) (Stein et al. 2007), and neuroimaging studies suggest that similar brain areas that are involved in other forms of anxieties such as amygdala (e.g., Paulus and Stein 2006), prefrontal areas (e.g., Bishop 2009), bilateral inferior frontal junction (Lyons and Beilock 2012), insula (Suárez-Pellicioni et al. 2016), and some subcortical regions that include caudate, nucleus accumbens, and hippocampus are activated when individuals experience math anxiety (Lyons and Beilock 2012).

1.21. Gender Differences in Math Anxiety

Else-Quest et al. (2010) meta-analysis showed that females are more susceptible to math anxiety than their male counterpart in math-related situations. Gender differences in math anxiety have been attributed to gender differences in self-concept, attitude, and gender stereotypes, with females having lower math-related self-concept (Hyde et al. 1990; Goetz et al. 2008), more negative attitude towards math (Watt 2004; Nagy et al. 2008), experience less pleasant emotions and derive less enjoyment from participating in math (Frenzel et al. 2007), and being more negatively impacted by gender stereotypes concerning math achievement (see Passolunghi et al. 2014; Steffens et al. 2010).

Math anxiety can be further divided into subtypes. However, different classifications were endorsed by different researchers. Some distinguished between math test anxiety vs. numerical anxiety (see Wilder 2012); some distinguished between affective (i.e., negative affective reactions to math-related activities in school) math anxiety vs. cognitive (i.e., concerns about math performance or tendency to worry in math learning situations) math anxiety (see Wigfield and Meece 1988); some proposed a trait vs. state distinction, with the former reflecting generalized perceptions of one's emotion and the latter reflecting real-life and in situ emotional experiences (see Bieg et al. 2015).

Using independent *t* tests, Wilder (2012) reported that female first- and second-year undergraduate students who were enrolled in math classes experienced a significantly higher level of math test anxieties than male students. Bieg et al. (2015) studied a sample of 755 German 9th and 10th graders and found that being female was associated with a higher level of math trait anxiety. However, in the same study, no gender differences were found for math state anxiety. Wigfield and Meece (1988) assessed math anxiety in children from grade 6 to grade 12. The researchers identified a negative affective reaction component and a cognitive component of math anxiety through confirmatory factor analysis. Males and females showed different profiles for these two components: on the one hand, girls had a reportedly stronger negative emotional reaction to math (see Ho et al. 2000, for a cross-cultural comparison study); on the other hand, no significant gender differences were found for the cognitive component of math anxiety (Wigfield and Meece 1988). The affective component was found to be more predictive of math achievement in both genders (Ho et al. 2000).

It should be noted that while many studies (e.g., Escalera-Chávez et al. 2017; Frenzel et al. 2007; Goetz et al. 2013; Hembree 1990) revealed a higher level of math anxiety experienced by females, there are also a handful of studies that failed to show gender differences in math anxiety (e.g., Haynes et al. 2004; Birgin et al. 2010). The discrepant findings across different studies could be due to a number of reasons: (1) as discussed previously, math anxiety is multifaceted. Different subtypes of math anxiety may have been the focus of the studies that revealed discrepant findings. Gender differences may be more pronounced in certain subtypes of math anxiety. (2) Gender differences in math anxiety may not be fully manifested until a certain grade level (age). For example, Malinsky et al. (2006) showed that gender differences emerge during secondary school years. (3) Attitude towards math, math self-concept, and other contextual variables may be confounding variables that influence the relationship between gender and math anxiety.

1.22. Spatial Ability and Math Anxiety

Maloney et al. (2012) suggested that low spatial ability individuals may be more challenged when solving math problems. Ferguson et al. (2015) showed that individuals with high math anxiety underperform on spatial ability tests. Using regression analyses, the study also showed that small-scale spatial ability is a robust predictor of math anxiety. Ashkenazi and Danan (2017) found that visuospatial working memory (VSWM), a closely related construct to spatial ability (see Wang et al. 2018), may be a source of vulnerability to math anxiety. Taken together, these studies suggest that spatial ability and math anxiety are inversely related.

While many studies that explored this link are not experimental studies, making it difficult to infer causal relationship between low spatial ability and high math anxiety, Maloney (2016) argued that math anxiety most likely results from difficulties in numerical skills (see Maloney et al. 2011) and spatial skills (Maloney et al. 2012) in early years of an individual's life. A longitudinal study would be helpful in determining the direction of influence between spatial ability and math anxiety. Ideally, spatial ability is to be measured before the onset of the math anxiety. It is predicted that those who started off with the poorest spatial ability proceed onto developing math anxiety in later years (Maloney 2016).

In the absence of experimental and longitudinal studies investigating the relationship between spatial ability and math anxiety, theoretically, it still makes more sense to consider low spatial ability to be preceding math anxiety, rather than vice versa (Maloney 2016). Thus, for the purpose of detecting potential mediation relationships, we consider models specifying low spatial ability being a precursor to high math anxiety to be the more plausible than the other way around. Nevertheless, we recognize the need for experimental and longitudinal studies on this relationship in the long run to completely rule out the alternative models that are not delved into in this review.

1.3. Math Achievement

Unlike math aptitude, which reflects potentials to do well in math learning situations, math achievement refers to the cumulative knowledge or problem solving skills that are gained from formal and informal math learning situations. Math achievement tests can be classified according to their cognitive demands (e.g., simple additions/subtractions, complex problem-solving), content areas (e.g., geometry, algebra), or general purposes (e.g., admissions, talent-identification). Math achievement tests reviewed in this section typically fall into one of these three categories.

1.31. Gender Differences in Math Achievement

Findings on gender differences in math achievement are not clear-cut in regard to different categories of math achievement tests. Also, more distant studies tend to show greater gender differences than more recent ones (Devine et al. 2018; Hyde et al. 2008; Scheiber et al. 2015). Hyde et al. (1990) meta-analyzed 100 studies (254 independent effect sizes) and showed a decline in gender differences in math problem solving skills over the years. Specifically, the effect size dropped from .31 for studies published before 1973 to .14, for studies published thereafter. Linn and Hyde's (1989) systematic review reached a similar conclusion. However, even decades-old studies reveal relatively small gender effect in favor of males' performance, as expressed by the effect size *d* (e.g., Hyde et al. 1990). Hyde et al. (1990) found that averaged over all effect sizes on gender differences in math achievement, *d* was − 0.05, indicating that gender differences are negligible. In a recent large-scale study involving a US stratified sample of children and adolescents, age ranged 6–21 years, and using individually administered measures of math achievement, Scheiber et al. (2015) did not find any gender differences in math achievement.

Furthermore, not all categories of math achievement consistently show the same degree of gender differences, with basic numerical skills (see Hutchison et al. 2018) and simple arithmetic problems showing the fewest gender differences, and complex problems showing the greatest gender differences (Lindberg et al. 2010). In fact, females have been shown to have a slight advantage in solving computation problems (Lindberg et al. 2010). Similar to the literature on gender differences in spatial ability, gender differences in math achievement are more pronounced in high school years and beyond and are either non-existent or barely noticeable in elementary and middle-school years (Hutchison et al. 2018; Hyde et al. 2008; Lindberg et al. 2010). Hyde et al. (2008) meta-analyzed state test results from 7 million US students from grades 2 through 11. The state tests assessed lower level math skills and showed that across the grade levels sampled, effect sizes for gender differences ranged from − 0.02 to + 0.06. Lindberg et al. (2010) meta-analyzed 242 studies published between 1990 and 2007 and came to the same conclusion: gender differences in math achievement are negligible in the realm of basic math skills ($d = 0.05$) and small ($d = 0.16$) in realm of complex problems, at least as far as the US samples are concerned.

Studies featuring international samples, on the other hand, show more variability in the magnitude and direction of gender differences across different nations (Hyde 2014). One reason for these variabilities could be that ethnicity may be interpreted differently across different cultural contexts or nationalities. Another reason could be due to the presence of confounding variables such as socioeconomic status (SES) or the interactivity among multiple variables (e.g., nationality, ethnicity, SES). These possibilities need to be considered and carefully controlled for in future studies of gender differences in math achievement featuring international samples. More studies are needed to further clarify the nature of gender differences across different categories of math achievement domains in an international context.

1.32. Spatial Ability and Math Achievement

Spatial ability is already implicated in math achievement in early childhood (see Verdine et al. 2014). This association is manifested at both the neural and the behavioral levels (see Clements and Sarama 2007a, 2007b; Robinson et al. 1996). Verdine et al. (2014), for instance, found that as early as 3 years of age, spatial assembly skills (as assessed by interlocking block construction task) already contributed a significant amount of variance in concurrent math achievement. Walsh (2003) proposes a theory of magnitude that elucidates the shared neural coding between number and space. This model shed light on the close relationship between numerical and spatial skills at the neural level. De Hevia et al. (2008) synthesized behavioral, neuropsychological, and neuroimaging studies and reached the same conclusion as what Walsh's (2003) model would suggest, i.e., in the realm of numerical and spatial cognition research, there is compelling evidence demonstrating that numerical and spatial representations are closely related. Specifically, these researchers argued that number and space are linked at the neural level through an imaginary mental number line where numerical magnitude is mapped onto an analogue spatial representation. This mapping is instantiated by the intraparietal sulcus (IPS) (see Fias et al. 2007; Fias et al. 2003, for evidence concerning IPS activation during numerical processing). In addition, number and space are also linked through visuospatial representation of numerical codes (see also Dehaene et al. 1999; Dehaene et al. 1996).

Further evidence supporting the link between spatial ability and math achievement is compiled in a comprehensive review by Mix and Cheng (2012), which reviewed developmental/longitudinal and educational intervention studies on spatial ability and its implications in concurrent or future math achievement. Along with the studies reviewed by Mix and Cheng (2012), one source of behavioral evidence connecting number and space comes from longitudinal predictive studies. Casey et al. (2015) investigated early predictors (information collected at the 1st grade) of 5th grade math achievement in spatial (geometry/measurement) and analytical (number/algebra) reasoning in 79 school girls. Among 1st grade verbal skills, arithmetic skills, and spatial skills, 1st grade spatial skills were the best predictors of 5th grade math achievement in both spatial and analytical reasoning. Krinzinger et al. (2015) used structural equation modeling method to analyze the impacts of attitudes towards math, visuospatial working memory (as measured by forward and backward Corsi blocks tapping) and visuospatial abilities (as measured by visuo-motor integration and visual perception) in 1st grade on multi-digit number processing at the end of 3rd grade. In the 140 primary school children tested, early visuospatial abilities were found to predict later multi-digit number processing. The authors attributed the connection between multi-digit processing and spatial ability to the regularity of "place-value system." Using a sample of Finnish children age ranged from 6 to 10 and a longitudinal design, Zhang et al. (2014) found that spatial visualization, measured in kindergarten, predicted 1st grade arithmetic achievement and its growth through 3rd grade. Thus, longitudinal studies on the developmental trajectories of spatial and numerical skills typically support the notion that early spatial ability is an important predictor of later math achievement.

The final source of behavioral evidence supporting the close relationship between spatial ability and math achievement reviewed here comes from interventional studies. Cheng and Mix (2014), for instance, reported that a 40-min mental rotation training improved children, age ranged from 6 to 8 years, in their performance in solving missing terms problems. However, Hawes et al. (2015), who administered computerized mental rotation training in the experimental condition and literacy training in the control condition, failed to find a transfer of spatial ability training to math achievement after a 6-week training session. More recently, Hawes et al. (2017) administered a 32-week training program that features a dynamic spatial visualization intervention program in K-2 classrooms. These researchers found that comparing with an active control group, children in the intervention condition improved in spatial language, spatial reasoning, and two-dimensional mental rotation performance. The spatial visualization intervention was administered as a part of the standard math instruction and showed a transfer of training effect from the visuospatial domain to the numerical domain. Specifically, students in the spatial intervention condition outperformed those in the active control condition in symbolic number comparison task performance. In the same vein, another recent intervention study by Lowrie et al. (2017), who administered a classroom-based spatial reasoning intervention to 10–12 year olds over the course of 10 weeks, found that the spatial training program led to a transfer of training effects from the spatial to the numerical domain. At the end of that training program, students in the spatial reasoning intervention program outperformed the control condition not only on designated spatial tests, but also in solving certain types of math problems.

Overall, there is some evidence suggesting a transfer of training effect from the spatial to the mathematical domain from recent intervention studies targeting various types of spatial skills. Because spatial ability is malleable to training (see Uttal et al. 2013) and gender differences in spatial ability is well documented (Voyer et al. 1995), intervention programs targeting spatial ability may hold a key to ensuring gender equity in STEM education and access to STEM careers (see Cherney et al. 2014; Tzuriel and Egozi 2010 for evidence showing the effectiveness of spatial intervention programs in reducing gender gaps in spatial skills). Newcombe (2017) specifically argued that there are two main routes through which spatial ability intervention may benefit STEM education: one is through a direct transfer of spatial ability training to solving math and science problems involving visuospatial thinking; the other is through "spatializing" the curriculum by incorporating spatial materials into the existing STEM curriculum.

1.33. Math Anxiety and Math Achievement

Both individual factors (e.g., cognitive, affective, motivational) and contextual factors (e.g., students' perceived classroom environment, teachers' math anxiety, parents' math anxiety) contribute to the negative correlation between math anxiety and math achievement (see Fig. 1, Chang and Beilock 2016). Foley et al. (2017) concluded that existing evidence cannot ascertain whether the direction of influence between math anxiety and math achievement is from the former to the latter, vice versa, or bidirectional. These researchers reasoned that math anxiety may impact math achievement by depleting working memory resources (see also Ashcraft and Kirk 2001), disrupting attention control mechanism (Suárez-Pellicioni et al. 2016), or by disrupting numerical representation (Maloney et al. 2011; Suárez-Pellicioni et al. 2016). Low prior math achievement may lead to increased math anxiety by lowering self-efficacy (for an account of the "debilitating theory," see Carey et al. 2016), or by decreasing perceived self-competency (see Jansen et al. 2013). Math anxiety and math achievement may be bi-directionally influencing each other through a vicious or a virtuous feedback loop (Carey et al. 2016; Foley et al. 2017; Gunderson et al. 2018).

While the direction of influence between math anxiety and math achievement is not made entirely clear by prior research (Foley et al. 2017), prevailing evidence indicates that math anxiety and math achievement are inversely related to each other (however, see Meece et al.

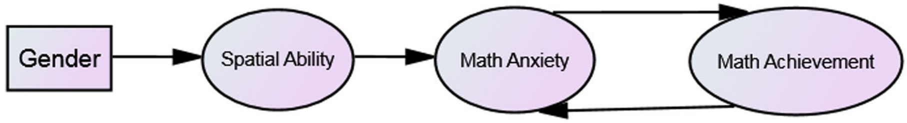

Fig. 1 Proposed model

1990, for counterevidence that indicates math anxiety not having significant direct effects on either math grades or math course enrollment intentions). The negative association is manifested in both males and females (see Ho et al. 2000), in a sample of engineering and technical undergraduate students, who presumably have higher math achievement than the average young adult population (Cooper and Robinson 1989), different age groups (evidence for elementary school children, see Cargnelutti et al. 2017; Jansen et al. 2013; evidence for secondary school students, see Cheema and Sheridan 2015; Hill et al. 2016; Malinsky et al. 2006; Meece et al. 1990; evidence for college students, see Andrews and Brown 2015; Núñez-Peña et al. 2013), and in performance on solving different types of math problems (for simple and complex additions, see Faust et al. 1996; for pre-algebra problems, see Andrews and Brown 2015).

Hypothetical Pathways Among Gender, Spatial Ability, Math Anxiety, and Math Achievement

Gender, Spatial Ability, and Math Anxiety

Maloney et al. (2012) argued that gender differences in math anxiety may at least be partially attributed to gender differences in spatial ability. Gender differences in spatial ability and visuospatial working memory (VSWM) are well documented (see Loring-Meier and Halpern 1999; Vecchi and Girelli 1998; Voyer et al. 1995; Voyer et al. 2017), with males showing an advantage. As reviewed previously, there is also accumulating evidence for gender differences in math anxiety, with females being more likely to experience math anxiety or experiencing a higher level of math anxiety than males (see Frenzel et al. 2007; Goetz et al. 2013; Hembree 1990; Malinsky et al. 2006). By this line of reasoning, spatial ability can be conceived as mediating the relationship between gender and math anxiety. Maloney et al. (2012) directly tested this mediational relationship in two populations. One population involves a college sample (study 1) and the other population involves a more diverse adult sample (study 2). The results of both studies suggest that spatial ability is inversely related to math anxiety and that the effect of gender on math anxiety is completely mediated by spatial ability (see Fig. 1, Maloney et al. 2012). Maloney et al. (2012) noted that due to the correlational design of the study, a causal relationship between spatial ability and math anxiety cannot be determined. Experimental studies are needed to rule out alternative models implying a reversed directional relationship between spatial ability and math anxiety or a reciprocal relationship between the two variables. In the context of prior findings concerning the two variables, these researchers reasoned that existing evidence is more in favor of a model postulating the direction of influence from spatial ability to math anxiety. Specifically, Maloney (2016) argued that poor spatial ability in early years may trigger math anxiety in math learning and testing situations later in life. The empirical evidence backing this hypothesis is that: On the one hand, gender differences in spatial ability are observed as early as 5 months of age (Moore and Johnson

2008) and those differences persist, if not increase, after early childhood (Mortensen et al. 2003). On the other hand, gender differences in math anxiety are not fully expressed until middle and high school years. The onset of math anxiety is comparably later in development than the onset of gender differences in spatial ability. Therefore, existing evidence best supports a model that postulates gender differences in math anxiety being best explained by gender differences in spatial ability. In other words, in the potential causal chain of effect embodied by the hypothetical mediation model, it is more logical to assume that spatial ability mediates the relationship between gender and math anxiety, rather than math anxiety being the mediator between gender and spatial ability.

Gender, Math Anxiety, and Math Achievement

The reviewed literature showed gender differences in math anxiety, which are most pronounced at and beyond the secondary school level. There is also some evidence for gender differences in math achievement, and especially for problem types involving visualizing and manipulating spatial relationships and for studies involving the US populations. Finally, there is evidence for an inverse relationship between math anxiety and math achievement. As argued by Maloney (2016), math anxiety may lead to underachievement in math, possibly by disrupting working memory resources (see Ashcraft and Kirk 2001; Ashcraft and Krause 2007). Conversely, underachievement in math may further increase math anxiety experienced in future math learning and testing situations. Therefore, it also makes sense to test a mediational relationship with math achievement serving as the mediator between gender and math anxiety. To our knowledge, this mediational relationship has not yet been directly tested. It is possible that the relationship between math anxiety and math achievement may be bidirectional or reciprocal, depending on the specific context and how the research question is framed. Finally, preliminary findings from Casey et al. (1997) study on a college sample and that used the mathematics portion of the Scholarly Aptitude Test (i.e., SAT-M) to measure math achievement did not find math anxiety to be statistically significantly mediating the relationship between gender and math achievement.

Spatial Ability, and Math Anxiety, Math Achievement

Prior research that investigated the relationship between spatial ability and math anxiety, between spatial ability and math achievement, and between math anxiety and math achievement in isolation revealed a positive association between spatial ability and math achievement, an inverse relationship between spatial ability and math anxiety, and between math anxiety and math achievement. Because math anxiety and math achievement can mutually feedback onto each other through either a vicious or a virtuous cycle, therefore, two possible mediational relationships can be derived from this set of variables. Either math anxiety or math achievement would serve as a mediator in the model.

Gender ➔ Spatial Ability ➔ Math Anxiety ←➔ Math Achievement

Based on the studies reviewed, the relationships among gender, spatial ability, math anxiety, and math achievement may be construed as the following chain of causal effects: gender impacts levels of math anxiety experienced through spatial ability, with females on average being more prone to math anxiety or experiencing a higher level of math anxiety than males, as a result of their lower average level of spatial ability. The lower average level of spatial ability exhibited by females in turn triggers their math anxiety in math learning and test-taking situations, where visualizing spatial relationships during math problem solving is vital to successful task completion or mastery learning experience. The heightened math anxiety, in turn, disrupts working memory resources and results in lower average math achievement in females than males. However, the chain of effect does not fully stop here, as low prior math achievement may result in more math anxiety in the future. Thus, for the sake of model testing, it would make sense to either test two separate models with a reversed direction of causality between math anxiety and math achievement, or to test a bidirectional relationship between math anxiety and math achievement within the same model.

Evaluation of the Proposed Model

In this review, distinct bodies of research that investigated gender differences in spatial ability, math anxiety, and math achievement, the relationship between spatial ability and math anxiety, between spatial ability and math achievement, and between math anxiety and math achievement were reviewed and the study findings were synthesized. As a result of this literature synthesis, a sequential mediation model involving the following causal chain of effects from gender to spatial ability, from spatial ability to math anxiety, and from math anxiety to math achievement (as well as in the reverse direction concerning the last pair of variables) is proposed for future testing. This model has the advantage of allowing simultaneous testing of two mediational relationships in the same model.

7One study that directly tested the mediation relationships among gender, math anxiety, spatial ability, and math achievement (as measured by SAT-M) (see Casey et al. 1997) did not find math anxiety to be a statistically significant mediator of the gender and math achievement (SAT-M) association, whereas spatial ability, as measured by mental rotation test, was found to be a significant mediator that explains 64% of the variance of the gender and math achievement (SAT-M) association. It should be noted that Casey et al. (1997) tested a parallel mediation model that simultaneously tested the significance of the mediators, i.e., spatial ability and math anxiety, between gender and math achievement. The relationship between spatial ability and math anxiety, however, was not specified in the parallel mediation model tested in Casey et al. (1997). A more recent study that tested the mediation relationship of spatial ability between gender and math anxiety (Maloney et al. 2012) found spatial ability to be a significant mediator of the relationship between gender and math anxiety. The possible mechanism through which this mediation relationship operates was elaborated on in Maloney (2016) as follows: being female is associated with lower spatial ability; early spatial ability is inversely related to levels of math anxiety experienced later in life. Though not directly tested in prior studies, Maloney (2016) reasoned that math anxiety is inversely linked to math achievement through a reciprocal feedback loop, after reviewing a body of literature involving these two variables. One reason why math anxiety fails to significantly mediate the relationship between gender and math achievement in Casey et al. (1997), despite the fact that such mediation relationship can be extracted from the results of prior studies, may be due to the parallel structure of the model tested in that study. The significance level of the mediators in the model may change, when the structure of the model changes from a parallel structure to a sequential structure, as is the case with the proposed model (gender➔spatial ability➔math anxiety ←➔math achievement).

In summary, the results of the studies reviewed lent a stronger support for some paths in the proposed model (e.g., gender➔spatial ability; spatial ability➔math anxiety; spatial ability➔math achievement; math anxiety➔math achievement) than others (e.g., gender➔math anxiety; gender➔math achievement; math achievement➔math anxiety). Nevertheless, the proposed sequential model makes it possible to empirically test two mediation relationships derived from prior research in the same model. In addition, the proposed model is consistent with Maloney's (2016) explanations in regard to the causal chain of effects among this set of variables. The theoretical importance of testing whether spatial ability mediates the relationship between gender and math anxiety is to gain a more thorough understanding of the mitigating factor of gender differences in math anxiety. Allowing bidirectional relationship between math anxiety and math achievement in the proposed model is theoretically meaningful and practically important in that it allows the researchers to anchor their model testing based on the specific research questions posed and the context in which the study takes place. The practical importance of testing potential mediation relationships among gender, spatial ability, and math anxiety is to inform educators of intervening variable that holds promise for reducing gender differences in math anxiety.

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