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Domain-specific Anxiety Relates to Children’s Math and Spatial Performance

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Abstract

Mathematical and spatial reasoning abilities during childhood predict later success in male-dominated science, technology, engineering, and math (STEM) disciplines, yet relatively little is known about the affective correlates of children’s math and spatial performance or gender differences therein. In the present research, we assessed math and spatial anxiety in 394 elementary-school children (ages 6 to 12 years) and investigated their relations to math achievement and spatial reasoning performance, respectively. In addition, we evaluated children’s verbal anxiety and reading ability to determine the domain specificity of relations between anxiety and cognitive performance during childhood. At the zero-order level, math, spatial, and verbal anxiety were moderately correlated with one another and with children’s performance in the corresponding cognitive domains. Importantly, however, all three forms of anxiety displayed some domain specificity in their relations to cognitive performance. Gender differences in math and spatial anxiety were also domain-specific, with girls reporting significantly greater math and spatial anxiety, but not verbal anxiety, across the age range tested. These results demonstrate that math and spatial anxiety represent unique constructs early in development, exhibiting specificity in their associations with gender and cognitive performance during the first years of formal schooling.

Keywords

math anxiety; spatial anxiety; gender differences; math achievement; spatial skill; childhood

A number of longitudinal studies have demonstrated a predictive relation between students’ early mathematical and spatial reasoning abilities and their later achievement in science, technology, engineering, and math (STEM) disciplines. For example, higher performance on mathematical and spatial reasoning tasks in adolescence is associated with greater academic and professional success in STEM fields in adulthood (Benbow & Arjmand, 1990; Kell, Lubinski, Benbow, & Steiger, 2013; Wai, Lubinski, & Benbow, 2005; Wai, Lubinski, & Benbow, 2009), and children’s mathematical and spatial reasoning abilities during the first years of formal schooling predict their later achievement in STEM domains (Casey et al., 2015; Gunderson, Ramirez, Beilock, & Levine, 2012a; Watts, Duncan, Siegler, & Davis-Kean, 2014). In addition to evidence that individual differences in math and spatial skills relate to STEM outcomes, prior findings also suggest that gender differences in math and

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spatial reasoning performance during adolescence contribute to gender disparities in students' STEM attainment (Casey, Nuttall, Pezaris, & Benbow, 1995; Ganley, Vasilyeva, & Dulaney, 2014; Wang, Degol, & Ye, 2015). Thus, research elucidating factors that contribute to both within- and between-gender variability in math and spatial performance during childhood has the potential to further our understanding of early barriers to STEM success.

Many individuals, particularly women, report feelings of apprehension when faced with tasks that require mathematical reasoning. This apprehension, referred to as math anxiety, is one affective factor known to relate to within- and between-gender variation in math achievement during adolescence and adulthood (Hembree, 1990; Ma, 1999). Spatial anxiety, which refers to feelings of apprehension provoked by activities that require spatial thinking, has similarly been shown to relate to individual and gender differences in spatial performance during adulthood (Ferguson, Maloney, Fugelsang, & Risko, 2015; Lawton, 1994). However, less is known about the development of individual and gender differences in these two forms of anxiety during childhood or their respective relations to children's mathematical and spatial aptitude. Thus, the present research was designed to examine the roles of math and spatial anxiety, as well as gender differences therein, in children's math and spatial performance across the elementary-school years.

Relation between Math Anxiety and Math Achievement Across Development

There is a well-established relation between math anxiety and math performance in adolescence and adulthood ($r_s \sim -.30$; for meta-analyses, see Hembree, 1990; Ma, 1999). Individuals with higher levels of math anxiety not only perform more poorly on standardized measures of math achievement in comparison to their less anxious peers (Ashcraft & Krause, 2007), but also report less positive attitudes towards math, avoid participation in math-related activities, and are less likely to enter mathematically-oriented STEM professions (Hembree, 1990; Chipman, Krantz, & Silver, 1992). The association between math anxiety and entry into the STEM workforce is particularly notable given that women report experiencing greater math anxiety than do men ($d_s = 0.19 - 0.31$; for meta-analysis, see Hembree, 1990), and this gender difference in math anxiety accounts, at least partially, for gender differences in adults' math performance (Ganley & Vasilyeva, 2014; Osborne, 2001). Although there is compelling evidence that math anxiety is one gender-linked trait with important implications for STEM attainment in adulthood, the developmental origins of individual and gender differences in math anxiety and their role in children's math performance have not yet been thoroughly characterized.

Prior studies on math anxiety in school-aged children have typically documented a negative association between math anxiety and math achievement when measured concurrently (Ganley & McGraw, 2016; Ramirez, Gunderson, Levine, & Beilock, 2013) and longitudinally (Cargnelutti, Tomasetto, & Passolunghi, 2017; Vukovic, Kieffer, Bailey, & Harari, 2013; but see Krinzinger, Kaufmann, & Willmes, 2009), suggesting that the negative relation between math anxiety and math achievement may be developmentally continuous across childhood and adulthood. In support of this contention, several studies have found

that the association between math anxiety and math achievement is particularly pronounced for children with high working memory (Ramirez, Chang, Maloney, Levine, & Beilock, 2016; Ramirez et al., 2013; Vukovic et al., 2013), mirroring findings of a moderating effect of working memory on the anxiety-performance link in adulthood (Ashcraft & Krause, 2007). Nevertheless, recent efforts to examine the predictive specificity of math anxiety during the elementary-school years have raised questions regarding the unique contribution of children's math anxiety in early math outcomes, limiting conjecture on the developmental continuity of the math anxiety-performance association.

In adolescence and adulthood, math anxiety is associated with, but distinct from, general anxiety (Hembree, 1990; Kazelskis et al., 2000; Wang et al., 2014) and other forms of domain-specific anxiety, including spatial anxiety (Malanchini et al., 2017). However, recent findings suggest that math anxiety may not yet be differentiable from other forms of anxiety during the elementary-school years. For example, Hill and colleagues (2016) reported that the relation between children's math anxiety and their math performance was no longer significant when controlling for general anxiety, introducing the possibility that math anxiety serves as a proxy for more domain-general forms of anxiety during childhood. In line with this account, Gunderson and colleagues (2018) found that children's math anxiety was negatively correlated with their math achievement and with their reading abilities during elementary school. If, as these findings suggest, math anxiety is not specifically associated with math performance during childhood, it would have substantial implications for our understanding of the affective correlates of children's math achievement as well as interventions targeted at reducing children's math anxiety. Nevertheless, no studies to date have examined the unique contributions of multiple forms of domain-specific anxiety in children's math performance, leaving open questions about the specificity of math anxiety and its relation to math achievement during the elementary-school years.

In addition to uncertainty regarding the specificity of the math anxiety-achievement relation, the extant literature has not addressed the specificity of gender differences in math anxiety during childhood or their developmental trajectory across the elementary-school years. Some studies have reported that, as in adulthood, female elementary-school students experience higher levels of math anxiety relative to their male peers (e.g., Devine, Fawcett, Szűcs, & Dowker, 2012; Gunderson, Park, Maloney, Beilock, & Levine, 2018; Hill et al., 2016), but other studies have not found gender differences in children's math anxiety (e.g., Ramirez et al., 2013; Vukovic et al., 2013). Moreover, it is unclear whether any observed gender differences in children's math anxiety are specific to the domain of mathematics as girls report greater test anxiety (Devine et al., 2012) and greater general anxiety (Hill et al., 2016) relative to boys in elementary school, indicating that gender differences in children's math anxiety could be attributable to gender differences in domain-general affective factors. Therefore, examining the presence and domain-specificity of gender differences in math anxiety across the elementary-school years will be necessary to characterize their developmental trajectory.

Research assessing gender differences in children's anxiety across multiple cognitive domains not only has the potential to illuminate the origins and development of gender differences in math anxiety but also to elucidate psychosocial and cognitive factors that

underlie their emergence in ontogeny. One prominent perspective on this topic proposes that gender differences in math anxiety arise because women are more comfortable reporting anxiety generally (for review, see Dowker, Sarkar, & Looi, 2016), a contention that is supported by evidence that women report greater general anxiety and greater test anxiety relative to men (Hembree, 1988). Others have argued that women experience greater math anxiety as a result of early-emerging gender stereotypes that women do not excel in mathematics (e.g., Beilock, Rydell, & McConnell, 2007). This suggestion has been corroborated by evidence of small, but significant stereotype-threat effects on women's math performance (for meta-analysis, see Doyle & Voyer, 2016) and that girls' math performance may also be susceptible to stereotype-threat effects during childhood (e.g., Ambady, Shih, Kim, & Pittinsky, 2001; Muzzatti & Agnoli, 2007; Tomasetto, Alparone, & Cadinu, 2011; but see Ganley et al., 2013). An alternative account argues that gender differences in math or spatial aptitude predispose women to experience greater difficulty with mathematical problem-solving, leading to their greater anxiety regarding math tasks (e.g., Maloney, Waechter, Risko, & Fugelsang, 2012). As these three accounts furnish differential expectations regarding the domain specificity of gender differences in math anxiety and math achievement during development, investigating the role of gender in children's anxiety and performance across multiple domains of cognition would contribute insight into the origins of gender differences in math anxiety.

The Role of Spatial Anxiety in Spatial Performance

In comparison to math anxiety, spatial anxiety remains a relatively unexplored topic across development. The few studies examining spatial anxiety in adulthood have found that individuals who experience greater spatial anxiety employ less efficient navigation strategies (e.g., Lawton, 1994) and exhibit poorer performance on mental rotation tasks that measure object-based spatial reasoning skills (Ferguson et al., 2015; Lawton, 1994; Lyons et al., 2018). Moreover, women have been found to report greater spatial anxiety relative to men (Ferguson et al., 2015; Lawton, 1994; Lyons et al., 2018). As is the case with math anxiety, it remains unclear whether gender differences in spatial anxiety result from the influence of domain-general factors (e.g., general or testing anxiety), early-emerging gender stereotypes regarding spatial intelligence (Neuburger, Ruthsatz, Jansen, & Quaiser-Pohl, 2015; Moè, 2018), or a male advantage in spatial reasoning performance (Voyer, Voyer, & Bryden, 1995), as no studies have yet examined gender differences in multiple forms of domain-specific anxiety during development. Given evidence that superior spatial abilities predict greater success in STEM fields (Kell et al., 2013; Wai et al., 2009) and that the male advantage in spatial performance contributes to gender disparities in STEM achievement (Casey et al., 1995; Ganley et al., 2014), research investigating the developmental origins of individual and gender differences in spatial anxiety would advance our understanding of one gender-linked predictor of STEM success.

To our knowledge, three published studies have assessed spatial anxiety prior to adolescence. First, Ramirez and colleagues (2012) tested the relation between spatial anxiety and mental rotation performance in first- and second-grade students. As with findings on math anxiety, the authors reported that greater spatial anxiety was associated with poorer mental rotation performance in children with high working memory, but not in those with

low working memory. Ramirez and colleagues (2012) found that girls reported greater spatial anxiety than boys, paralleling the gender difference in adults' spatial anxiety (Ferguson et al., 2015; Lawton, 1994). In a later study on third- and fourth-grade children, Cardillo and colleagues (2017) reported similar findings: spatial anxiety was negatively related to mental rotation performance, and girls reported greater spatial anxiety than boys. However, Cardillo et al. also found that children's spatial anxiety was negatively correlated with their verbal performance, suggesting that spatial anxiety may not represent a domain-specific construct during development. Moreover, in the only other published study on spatial anxiety in children, Wong (2017) did not document a significant relation between spatial anxiety and spatial performance or a gender difference in children's spatial anxiety. Thus, it remains unclear whether individual differences in spatial anxiety contribute to variability in children's spatial performance and whether gender differences in spatial anxiety are present in childhood.

Current Research

In the present research, we aimed to address the aforementioned gaps in the developmental literature by conducting a cross-sectional study of the correlates of math and spatial anxiety across the elementary-school years. This work was undertaken with three main objectives. First, we sought to characterize the relations between domain-specific anxiety and children's performance on measures of mathematical and spatial aptitude. Previous studies have raised questions about the specificity of these relations during childhood, reporting that general anxiety accounts for the effects of math anxiety on math performance in school-aged children (Hill et al., 2016) and that, at the zero-order level, math and spatial anxiety relate not only to young children's performance within the relevant cognitive domain but also to their verbal abilities (Cardillo et al., 2017; Gunderson et al., 2018). As no studies, to our knowledge, have assessed both math and spatial anxiety during childhood, prior research on this topic cannot address whether math and spatial anxiety are unique constructs during childhood that have specific implications for children's cognitive performance or whether these forms of anxiety do not become differentiated until later in development. Therefore, in the current study, we examined the associations between anxiety and performance within and across the domains of mathematical and spatial reasoning throughout the elementary-school years.

In addition to describing the domain specificity of the anxiety-performance association, we aimed to address the replicability of previous studies reporting that working memory moderates this relation during childhood (Ramirez et al., 2012; Ramirez et al., 2013) and to extend those findings across a broader range of development. To meet this objective, we explored whether relations between children's domain-specific anxiety and their cognitive performance varied as a function of working memory between Grades 1 and 5. Furthermore, given evidence that gender may influence the moderating role of working memory (Miller & Bichsel, 2004; Ramirez et al., 2012), we also considered gender as a potential moderator of both the anxiety-performance relation and its interaction with working memory.

The final objective of the present research was to chart the development of gender differences in math and spatial anxiety across the elementary-school years and to

characterize their domain specificity during childhood. As previously discussed, inconsistent reporting of gender differences in young children's math and spatial anxiety has limited our understanding of their developmental origins. Moreover, even when gender differences in children's math and spatial anxiety have been observed, it has not been evident whether these gender differences reflect the influence of domain-general factors that vary by gender (e.g., test anxiety) or whether they are indeed isolated to specific cognitive domains, such as those that are male-stereotyped or that produce gender differences in performance. To address these open questions, we assessed children's math and spatial anxiety as well as their anxiety pertaining to verbal reasoning, a cognitive domain that is female-stereotyped and typically shows a female advantage or no gender difference in performance (for meta-analyses, see Hyde & Linn, 1988; Lietz, 2006). We then examined gender differences in children's self-reported math, spatial, and verbal anxiety across Grades 1 through 5, allowing us to determine their domain specificity during childhood and to chart their developmental trajectory from the first years of formal education to the onset of adolescence.

Method

Participants

Participants were 394 elementary-school students (227 female) in Grades 1 through 5, ranging in age from 6 to 12 years ($M = 9.03$ years, $SD = 1.52$; see Table 1). Participants were recruited from a rural public school system in the southeastern United States. Consent forms were sent to the caregivers of all students along with a family demographics questionnaire. The sample consists of all children whose caregivers provided written informed consent and who completed each of the testing sessions (approximately 41% of the student population).

The family demographics questionnaire was returned for 90% of participants. The resultant data indicated that the sample was racially and ethnically diverse: caregivers identified their children as African-American (32%), Hispanic Caucasian (32%), non-Hispanic Caucasian (26%), multiracial (8%), Native American or Alaskan Native (1%), and other (1%). Caregivers were also asked to report their highest level of education: 12% completed elementary school, 10% completed some high school, 43% completed high school or its equivalent, 16% possessed a technical or associates degree, 13% possessed a bachelor's degree, and 6% possessed a graduate degree.

Children received a small toy and pencil for participating, and caregivers who completed the family demographics questionnaire were compensated with a \$10 gift card. All procedures were approved by the Emory University institutional review board (Protocol #5823, "Event Memory") and the school board.

Materials and Procedure

Data were collected at three time points during the spring semester of the school year. First, during the initial testing session, children completed a spatial reasoning task in their classrooms. Second, during the week following the initial testing session, children

completed a working memory task and a self-report anxiety measure individually with an experimenter in a quiet area of the school. The working memory task was administered at the beginning of the second testing session; the anxiety measure was administered at the conclusion of the session, so as not to interfere with children's performance on other tasks. Experimenters also collected data for an unrelated longitudinal study during the two testing sessions; consequently, each session lasted between 30 and 40 minutes. Third, at the conclusion of the semester, school principals reported children's scores on their end-of-year standardized math and reading assessments.

Anxiety Scale.

Children were administered a 15-item questionnaire that assessed their anxiety pertaining to three cognitive domains: math, spatial, and verbal reasoning. The design of the anxiety measure was modeled after the Children's Math Anxiety Scale (Ramirez et al., 2013) and the Children's Spatial Anxiety Scale (Ramirez et al., 2012). Specifically, children were presented with various scenarios that required the use of problem-solving abilities (i.e., math, spatial, or verbal skills), and after hearing each scenario, children were instructed to use a sliding scale to indicate how nervous they would feel when encountering the given scenario. An emoji with a neutral expression was positioned at the left end of the sliding scale, an emoji with a slightly nervous expression was positioned at the center of the scale, and an emoji with a very nervous expression was positioned at the right end of the scale. The measure was computerized for touchscreen administration using custom Visual Basic (Microsoft) script, and children used the sliding scale on a touchscreen laptop to respond to each item. Children's responses were measured continuously from 0 (neutral) to 100 (very nervous), such that a higher score indicated greater anxiety. Prior to administering the task, the experimenter familiarized the child with the sliding scale and presented example scenarios (e.g., looking over the side of a tall building) with corrective feedback to ensure that the child understood task instructions.

The anxiety measure consisted of 15 scenarios: five required mathematical thinking (e.g., counting change, solving an arithmetic problem), five required spatial reasoning (e.g., giving directions, building a tower from a model), and five required literacy and/or verbal abilities (e.g., reading aloud, completing a crossword puzzle). Scenarios pertaining to math and spatial anxiety were derived from the Children's Math Anxiety Scale (Ramirez et al., 2013) and the Children's Spatial Anxiety Scale (Ramirez et al., 2012). The Children's Verbal Anxiety Scale was developed for this research and was comprised of verbal anxiety scenarios that matched the wording of the scenarios presented in the math and spatial anxiety items. In addition, the setting of the five scenarios were matched across domains such that three scenarios for each domain would be likely to occur in a classroom setting (e.g., a question posed by a teacher, a classroom examination) and two scenarios for each domain would be likely to occur outside of the classroom (e.g., paying for a candy bar, giving directions). The scenarios were presented to children in a random order with the constraint that no more than two scenarios pertaining to a given domain were presented sequentially. Children's responses to all items within each domain (i.e., math, spatial, or verbal) were averaged to compute a mean math, spatial, and verbal anxiety score for each child. The math, spatial, and verbal items each produced adequate reliability (Cronbach's

alphas = .53 - .56; ω s = .60 - .72), similar to previous studies that have administered math and spatial anxiety questionnaires to young children (Ramirez et al., 2012; Ramirez et al., 2013; Wong, 2017), and the reliability of the three anxiety measures did not vary by grade level (χ^2 s < 8.36, p s > .08).

Math achievement.

Children's math achievement was measured via their end-of-year scores on the mathematics portion of the i-Ready, a nationally standardized math assessment based on the Common Core State Standards (Curriculum Associates, 2017). The assessment is a computer-based adaptive measure and consists of 54 to 72 questions depending upon children's performance. In the grade levels tested, questions evaluate math abilities in diverse domains including arithmetic, measurement, geometry, and algebraic thinking.

Spatial reasoning.

Children's spatial reasoning performance was measured via a mental rotation task, namely the Primary Mental Abilities-Spatial Relations subtest (Thurstone & Thurstone, 1974). Each item in the task consists of a target shape and four choice shapes; children must indicate the choice shape that can be rotated to form a square with the target shape. The measure was administered in children's classrooms. Before beginning the task, children completed four example items, and the experimenter provided corrective feedback. Children were then given four minutes to complete 24 items. Task performance was measured by subtracting the number of incorrect responses from the number of correct responses for each child (Thurstone & Thurstone, 1974).

Reading ability.

Children's reading ability was measured via their end-of-year scores on the Scholastic Reading Inventory, a nationally standardized assessment used to evaluate reading fluency and comprehension (Scholastic Reading Inventory, 1999). The Scholastic Reading Inventory is a computer-based adaptive measure, and children complete between 29 and 82 questions depending on their reading proficiency. Children in first grade are not administered this measure in the participating school system, so analyses including Scholastic Reading Inventory data only pertain to children in Grades 2 through 5 ($N = 316$).

Working memory.

Children's working memory was measured via the Corsi Block Test from the PEBL test battery (Mueller & Piper, 2014). During each trial of this task, children were presented with nine squares on a touchscreen computer, and a subset of the squares changed color one at a time after which children were directed to touch each square that changed color in reverse order. On the first trial, two squares changed color. After two consecutive trials were correctly completed, the number of squares that changed color increased by one, and the task terminated once children answered two trials incorrectly. Children's block span was used to evaluate their performance.

Data Analyses

First, children's scores on all measures were transformed into standard scores (z -scores) based on the performance of all participants in their grade in order to control for the expected age-related increases in task performance (see Table S1 for descriptive statistics on unstandardized scores by grade level). Second, we conducted a series of zero-order correlation analyses to characterize the associations among the three different forms of domain-specific anxiety assessed. Follow-up analyses were then performed to determine whether the relations among math, spatial, and verbal anxiety differed by grade level and gender. Next, we examined the bivariate correlations between the three types of domain-specific anxiety measured and children's performance on the math, spatial, and reading assessments. A series of multiple regression analyses was then conducted to evaluate the specificity of the anxiety-performance association and age-related change in its magnitude across domains as well as the moderating effects of gender and working memory. Finally, we conducted two-sample t -tests to examine the role of gender in children's anxiety and performance and analyses of covariance to assess age-related change in the effect of gender across tasks.

Results

Relations Among Math, Spatial, and Verbal Anxiety

Children's math, spatial, and verbal anxiety scores were positively correlated with one another ($r_s > 0.37$, $p_s < .001$; see Table 2). These interrelations were not moderated by grade ($R^2_s < 0.01$, $F_s < 2.12$, $p_s > .14$) and did not differ by gender (Fisher's $Z_s < 1.61$, $p_s > .10$), suggesting that, as in adulthood (Ferguson et al., 2015; Malanchini et al., 2017), there are moderate correlations among different forms of domain-specific anxiety across the elementary-school years. These findings are consistent with the contention that individual differences in children's math and spatial anxiety may be influenced by domain-general forms of anxiety regarding evaluative situations or tasks that require problem-solving skills (e.g., test anxiety).

Relation between Math Anxiety and Math Achievement

At the zero-order level, greater math anxiety [$r(392) = -.19$, 95% CI $(-.28, -.09)$, $p < .001$; see Figure 1A] and greater verbal anxiety [$r(392) = -.20$, 95% CI $(-.29, -.10)$, $p < .001$] were both associated with lower standardized math scores, whereas spatial anxiety was not related to math performance [$r(392) = -.05$, 95% CI $(-.14, .05)$, $p = .365$]. As these findings left open the possibility that domain-general factors (e.g., test anxiety) led to the observed relation between math anxiety and math performance, we next considered the extent to which math anxiety uniquely related to math achievement when accounting for the effects of the other two domain-specific anxieties assessed. Specifically, we conducted a multiple regression analysis that included math, spatial, and verbal anxiety as predictors of children's standardized math performance, and gender and grade as covariates (see Table 3), finding that, similar to the pattern of zero-order correlations, math anxiety and verbal anxiety scores were significantly associated with math achievement, but spatial anxiety scores were not (Table 3, Model 1). Although these results suggest that both math and verbal anxiety may have contributed to variability in children's math scores, a follow-up analysis revealed that

verbal anxiety was only associated with math achievement due to its relation to reading ability (see Figure S2 for mediation analysis). That is, when controlling for children's reading ability, math anxiety remained significantly correlated with children's math performance ($\beta = -.14$, $t = -2.70$, $p = .007$; see Table S3), but verbal anxiety did not ($\beta = -.01$, $t = -0.21$, $p = .836$; see Table S3). Thus, when accounting for other types of domain-specific anxiety and children's reading skills, math anxiety was the only unique predictor of children's standardized math scores.

We next examined the developmental trajectory of the relations between the three forms of domain-specific anxiety assessed and math achievement. Specifically, we conducted a multiple regression analysis that evaluated grade level as a moderator of the effects of math, spatial, and verbal anxiety on children's standardized math performance, again including gender and grade as covariates (see Table 3, Model 2). This analysis revealed that the negative relation between math anxiety and math achievement was more pronounced in older children than in younger children ($\beta = -.28$, $t = -2.10$, $p = .037$; see Figure 2). In contrast, grade level did not significantly moderate the relation between spatial anxiety and math performance ($\beta = .22$, $t = 1.77$, $p = .078$) or the relation between verbal anxiety and math performance ($\beta = .16$, $t = 1.24$, $p = .215$). These results provide preliminary evidence that the relation between math anxiety and math achievement increases in magnitude across the elementary-school years.

In a final set of analyses examining children's math achievement, we assessed the potential roles of working memory and gender as moderators of the math anxiety-performance association (see Table S4 for regression table). Contrasting previous findings in school-aged children (Ramirez et al., 2013, Ramirez et al., 2016), working memory did not moderate the relation between math anxiety and math achievement ($\beta = .03$, $t = 0.59$, $p = .557$; see Figure 3A). We also found no moderating effect of gender ($\beta = .03$, $t = 0.67$, $p = .504$), as has been found in adulthood (Hembree, 1990; Miller & Bichsel, 2004), nor any interaction between math anxiety, working memory, and gender ($\beta = .06$, $t = 1.30$, $p = .196$). See the Supplemental Materials for further analyses that consider the moderating effects of working memory and gender in this sample.

Relation between Spatial Anxiety and Spatial Performance

Zero-order correlation analyses indicated that math, spatial, and verbal anxiety were negatively correlated with spatial reasoning performance ($r_s < -.11$, $p_s < .03$; see Table 2, Figure 1B]. To examine the specificity of the spatial anxiety-spatial performance relation, we conducted a multiple regression analysis that included math, spatial, and verbal anxiety as predictors of children's spatial reasoning scores, including gender and grade as covariates (see Table 4). This analysis revealed that math, spatial, nor verbal anxiety accounted for unique variability in spatial performance when controlling for the other domain-specific anxieties assessed ($p_s > .15$; Table 4, Model 1). Furthermore, grade level did not moderate the relations between math, spatial, or verbal anxiety and spatial reasoning performance ($p_s > .74$; Table 4, Model 2). Taken together, these findings suggest that the bivariate correlation between spatial anxiety and spatial performance observed in adulthood (e.g., Ferguson et al.,

2015; Lawton, 1994) is present throughout the elementary-school years, but spatial anxiety may not uniquely predict spatial performance during this period of development.

We next examined the potential moderating roles of working memory and gender in the relation between spatial anxiety and spatial performance (see Table S5 for full regression models). Neither working memory nor gender moderated the spatial anxiety-performance association ($ps > .59$; Table S5; see Figure 3B), and there was no significant three-way interaction between spatial anxiety, working memory, and gender ($\beta = .03$, $t = 0.49$, $p = .623$). These results contrast those of Ramirez and colleagues (2012) who reported that the negative effects of spatial anxiety on performance were most pronounced in young girls with high working memory (see Supplemental Materials for additional relevant moderation analyses).

Relation between Verbal Anxiety and Reading Ability

Zero-order correlation analyses indicated that greater math anxiety [$t(314) = -.17$, 95% CI $(-.27, -.06)$, $p = .003$] and greater verbal anxiety [$t(314) = -.25$, 95% CI $(-.35, -.14)$, $p < .001$] were associated with poorer reading comprehension (Table 2, see Figure 1C), whereas spatial anxiety was not correlated with reading performance [$t(314) = -.07$, 95% CI $(-0.18, 0.04)$, $p = .239$]. To examine the specificity of verbal anxiety as a correlate of children's reading abilities, we conducted a multiple regression analysis that included math, spatial, and verbal anxiety as predictors of reading performance and gender and grade as covariates (see Table 5). This analysis revealed that verbal anxiety scores accounted for unique variance in children's reading performance ($\beta = -.23$, $t = -3.65$, $p < .001$), but math and spatial anxiety scores did not ($ps > .18$; Table 5, Model 1). An additional analysis indicated that the relations between anxiety and reading performance did not vary by grade level for any of three forms of anxiety assessed ($ps > .16$; Table 5, Model 2). These results demonstrate that, despite being strongly associated with other forms of domain-specific anxiety, verbal anxiety displays specificity in its relation to reading achievement between Grades 1 and 5.

Finally, we assessed the influence of working memory and gender on the relation between verbal anxiety and reading performance (see Table S6). We found no moderating effects of working memory or gender ($ps > .57$; Table S6; Figure 3C) and no significant three-way interaction between verbal anxiety, working memory, and gender ($\beta = .00$, $t = 0.08$, $p = .940$). Thus, similar to our results on math and spatial anxiety, we found no evidence that working memory or gender moderated the relation between verbal anxiety and reading ability.

Gender Differences in Domain-Specific Anxieties and Task Performance

Girls reported experiencing greater math anxiety [$t(392) = 3.21$, $p = .001$, $d = 0.33$] and greater spatial anxiety [$t(392) = 3.64$, $p < .001$, $d = 0.37$] relative to boys, yet there was no gender difference in children's verbal anxiety [$t(392) = 0.91$, $p = .366$, $d = 0.09$] (see Figure 4; see Table S2 for descriptive statistics by gender). The relation between gender and anxiety did not vary by grade within any of the three domains ($F_s < 1.77$, $ps > .18$, $\eta^2_p s < 0.01$; see Figure S3), indicating that girls experienced greater math and spatial anxiety, but not verbal

anxiety, across the elementary-school years. These findings align with previous research reporting small to moderate gender differences in math anxiety (Hembree, 1990) and spatial anxiety in adulthood (e.g., Lawton, 1994; Ferguson et al., 2015; Lyons et al., 2018) to put forth the possibility that gender differences in math and spatial anxiety emerge early in childhood and persist across development.

There were no significant gender differences in children's math achievement [$t(392) = 0.12$, $p = .903$, $d = 0.01$], spatial reasoning skills [$t(392) = -0.46$, $p = .643$, $d = -0.05$], reading abilities [$t(314) = -0.25$, $p = .804$, $d = -0.02$], or working memory performance [$t(392) = 0.52$, $p = .600$, $d = 0.05$], and grade level did not moderate the relation between gender and performance on any of these measures (p s > .28, η^2_p s < .01). Thus, girls reported greater math and spatial anxiety in the absence of gender differences in performance within these domains. Moreover, gender differences in math anxiety [$F(1, 308) = 8.13$, $p = .005$, $\eta^2_p = .03$] and spatial anxiety [$F(1, 308) = 4.43$, $p = .036$, $\eta^2_p = .01$] remained significant even when accounting for children's anxiety in the other two domains assessed and their performance on the math, spatial, reading, and working memory measures. Therefore, it is unlikely that girls reported greater math and spatial anxiety relative to boys because they experienced greater difficulty with math and spatial reasoning tasks.

Discussion

In the present study, we examined individual and gender differences in domain-specific anxiety and their associations with children's math achievement, spatial reasoning performance, and reading ability across the elementary-school years. In a large, diverse sample of children aged 6 to 12 years, we found that math, spatial, and verbal anxiety displayed some specificity in their relations to children's performance in the corresponding domain of cognition. Moreover, we found that gender differences in children's self-reported anxiety were specific to male-stereotyped cognitive domains (i.e., math and spatial reasoning) across the age range tested, even though children's math and spatial performance did not vary by gender. These results suggest that individual and gender differences in math and spatial anxiety during childhood may act as precursors of later within- and between-gender variation in cognitive performance.

Specificity in the Roles of Math, Spatial, and Verbal Anxiety in Cognitive Performance

The current study is the first to measure multiple types of domain-specific anxiety in elementary-school children and to assess their associations with performance across cognitive domains, providing insight into the specificity of math, spatial, and verbal anxiety during development. We observed moderate correlations among the three anxiety measures, suggesting that inter-individual variability in children's domain-specific anxiety may be influenced by individual differences in domain-general factors, such as test anxiety. Critically, however, math, spatial, and verbal anxiety all exhibited some domain specificity in their relations with children's math achievement, spatial performance, and reading ability.

First, we found that greater math anxiety was associated with poorer math achievement, even when controlling for spatial and verbal anxiety. Verbal anxiety was also correlated with math achievement at the zero-order level, but importantly, math anxiety was the only

significant predictor of children's math performance when accounting for the other domain-specific anxieties assessed and their reading abilities, demonstrating that math anxiety represents a unique source of variability in children's math achievement. Interestingly, we also found that the association between math anxiety and math achievement was more pronounced in older children than in younger children. These results put forth the possibility that a specific relation between math anxiety and math achievement emerges during childhood and that relevant academic experiences may foster the development of the math anxiety-achievement link across the elementary-school years.

Our findings replicate and extend those of prior studies using similar measures to assess math anxiety in first and second grade children (e.g., Ramirez et al., 2013; Ramirez et al., 2016), demonstrating that the negative association between math anxiety and math achievement is not only present but also domain specific during elementary school. However, in contrast to previous studies, we did not find evidence that the math anxiety-achievement association varied by working memory capacity. A potential source of this discrepancy may lie in our use of a visuospatial working memory measure to evaluate children's working memory, rather than a verbal working memory task as used by Ramirez and colleagues. In support of this contention, findings on adults suggest that increased anxiety may be particularly detrimental to math performance on problems that require verbal rather than spatial problem-solving (Beilock et al., 2007; DeCaro, Rotar, Kendra, & Beilock, 2010). Nonetheless, Miller and Bichsel (2004) demonstrated that visuospatial working memory, but not verbal working memory, influenced the association between adults' math anxiety and their math performance, and Vukovic and colleagues (2013) found that visuospatial working memory moderated the longitudinal relation between children's math anxiety and their math performance when measured one year later, providing conflicting evidence on the respective influences of visuospatial and verbal working memory across development. Thus, future research examining the moderating effects of both verbal and visuospatial working memory will be necessary to understand the influence of working memory on the math anxiety-achievement association.

In addition to findings of specificity in the domain of mathematics, we also documented some specificity in the relation between spatial anxiety and spatial performance, as greater spatial anxiety was associated with poorer spatial reasoning performance, but not math achievement or reading ability, at the zero-order level. Nevertheless, the spatial anxiety-performance relation was small in magnitude and was no longer significant when controlling for the effects of math and verbal anxiety, aligning with results of previous studies reporting small or negligible correlations between spatial anxiety and spatial reasoning during childhood (Ramirez et al., 2012; Wong, 2017). When compared with evidence of a moderate correlation between spatial anxiety and spatial performance in adulthood (Ferguson et al., 2015; Lawton, 1994; Lyons et al., 2018), these findings introduce the possibility that the relation between spatial anxiety and spatial reasoning becomes more pronounced between late childhood and early adulthood. Therefore, studies that examine the nature of this association during adolescence may be particularly informative to characterizing the developmental trajectory of the spatial anxiety-performance link.

Similar to our findings on math performance, we found no evidence that gender or working memory moderated the relation between spatial anxiety and spatial performance. These results differ from those of Ramirez and colleagues (2012), who reported that the spatial anxiety-performance association was only present in girls with high working memory capacities. Again, one potential explanation for these differing findings may be our use of a visuospatial working memory task, as Ramirez et al. employed a verbal working memory task to assess working memory. Because no other studies, to our knowledge, have examined the spatial anxiety-performance link in relation to working memory during elementary school, additional research will be necessary to address this possibility.

Although the observed correlation between spatial anxiety and spatial reasoning ability was small in magnitude, we believe that its stability across gender, age, and working memory capacity demonstrates the predictive power of spatial anxiety in children's spatial reasoning performance and calls for further exploration of the development of spatial anxiety. In the present research, children's spatial anxiety was measured in response to scenarios that required diverse types of spatial thinking (e.g., mental manipulation, navigation), and spatial performance was evaluated via a measure of mental rotation skills. However, factor analyses have indicated that spatial anxiety is a multifaceted construct in adulthood, finding that spatial anxiety induced by tasks that require navigation abilities can be differentiated from spatial anxiety induced by tasks that require spatial visualization skills (Malanchini et al., 2017; Lyons et al., 2018), and spatial ability has long been considered to be a multidimensional construct in adulthood (Carroll, 1993; Hegarty & Waller, 2004; Wang, Cohen, & Carr, 2014). The design of the current study did not allow us to consider the factor structure of children's spatial anxiety or the extent to which spatial anxiety differentially relates to children's performance on varying spatial measures (e.g., navigation tasks, spatial visualization tasks). Consequently, investigating multiple components of spatial anxiety and their relations to different forms of spatial performance during childhood will be a promising direction for future research on this topic.

In parallel to the observed specificity in the effects of math and spatial anxiety, verbal anxiety accounted for unique variability in children's performance in the corresponding domain. Specifically, verbal anxiety was the only significant predictor of children's reading comprehension scores when accounting for other forms of domain-specific anxiety. We developed the verbal anxiety measure administered in the current study because such a measure allowed us to assess the domain specificity of individual and gender differences in children's math and spatial anxiety. However, the reported specificity in the relation between verbal anxiety and reading ability calls attention to the paucity of research on children's verbal anxiety. In comparison to studies on math and spatial anxiety, verbal anxiety and its effects on academic performance have rarely been studied, and the present research is the first, to our knowledge, to assess the specificity of verbal anxiety during elementary school. Thus, future studies examining the affective correlates of children's academic achievement may benefit from considering the role of verbal anxiety in relevant educational outcomes.

Although math, spatial, and verbal anxiety each exhibited some degree of discriminant validity as predictors of children's performance in the corresponding cognitive domain, it is important to note that we also observed moderate anxiety-performance relations across

domains. At the zero-order level, both math and verbal anxiety were correlated with children's math achievement, spatial reasoning performance, and reading abilities, and zero-order correlations between anxiety and performance tended to be similar in magnitude across the three domains examined. These cross-domain relations are perhaps unsurprising given the robust associations between math, spatial, and verbal anxiety observed in the current study, which align with prior research establishing moderate relations between domain-specific anxiety (e.g., math anxiety, spatial anxiety) and domain-general anxiety (e.g., test anxiety, general anxiety) later in development (Hembree, 1990; Kazelskis et al., 2010; Malanchini et al., 2017; Wang et al., 2014). Given that domain-general forms of anxiety are also associated with performance decrements across cognitive domains, these domain-general affective factors likely contributed to the anxiety-performance associations found in the present research. Thus, future examination of both domain-specific and domain-general influences on cognitive performance will be necessary to fully characterize the unique role of domain-specific anxiety in children's math, spatial, and reading skills. Furthermore, research identifying domain-general affective processes involved in the anxiety-performance relation may be especially useful in developing interventions that not only facilitate children's success on domain-specific tasks but also benefit educational outcomes across academic disciplines.

Gender Differences in Math and Spatial Anxiety

Previous studies on young children have provided conflicting evidence of gender differences in math and spatial anxiety during the first years of schooling (e.g., Gunderson et al., 2018; Ramirez et al., 2012; Vukovic et al., 2013; Wong, 2017), leaving open questions about the presence of such gender differences early in development. In our study, girls reported greater anxiety regarding math and spatial tasks, but not verbal tasks, between first and fifth grade. The finding that girls reported greater math and spatial anxiety coalesces with those of prior studies documenting gender differences in these forms of anxiety in adulthood (e.g., Ferguson et al., 2015; Ganley & Vasilyeva, 2014; Lawton, 1994) to suggest that gender differences in math and spatial anxiety emerge by elementary school and persist throughout development. Moreover, we found that girls and boys reported equivalent levels of verbal anxiety across the elementary-school years, demonstrating that gender differences in children's anxiety were specific to the domains of math and spatial reasoning.

What may account for early emerging gender differences in math and spatial anxiety? As previously discussed, it has been proposed that females have a greater propensity to report anxiety generally (Dowker et al., 2016), leading to gender differences in domain-general and domain-specific anxiety when measured via self-report. Our results do not support this proposal, as there were no gender differences in children's verbal anxiety. An alternative explanation is that early gender differences in math achievement and/or spatial aptitude induce gender differences in children's anxiety regarding their abilities within these domains, leading girls to report greater math and spatial anxiety. Our findings are not congruent with this conjecture as gender differences in math and spatial anxiety remained significant even when controlling for children's performance on the cognitive assessments. In fact, gender differences in children's math and spatial anxiety were detected in the absence of gender differences in their math and spatial performance, suggesting that gender

differences in math and spatial anxiety during childhood may act as developmental antecedents to gender differences in cognitive and motivational factors that are associated with math and spatial performance later in development.

In contrast to the perspectives above, our finding that gender differences in anxiety were specific to male-stereotyped domains (i.e., math, spatial reasoning) is directly compatible with the contention that cultural stereotypes regarding male superiority in certain cognitive domains increase girls' anxiety about their cognitive abilities (e.g., Bander & Betz, 1981; Eccles & Jacobs, 1986). In Western countries, school-aged children stereotypically associate males with math (Cvencek, Meltzoff, & Greenwald, 2011; Gunderson et al., 2012b; Passolunghi, Ferreira, & Tomasetto, 2014) and spatial competence (Moè, 2018), indicating that girls are aware of gender stereotypes regarding math and spatial performance relatively early in development. In light of previous findings, our results put forth the possibility that the observed gender differences in math and spatial anxiety may develop in concert with girls' awareness of relevant gender stereotypes during early childhood. However, previous research has not thoroughly explored the effects of girls' awareness of gender stereotypes on their anxiety regarding male-stereotyped domains, meaning future studies will be necessary to determine the validity of this account.

Limitations

There were limitations to the present research that should be considered when interpreting its findings. Most notably, the study's correlational design limited our ability to establish causality in the reported relations between anxiety and performance. We found that domain-specific anxiety was associated with cognitive performance within the first years of formal schooling, which suggests that the anxiety-achievement link develops prior to the accumulation of significant academic experience in the cognitive domains evaluated. Nevertheless, it is possible that children who encountered difficulty with mathematical, spatial, or verbal reasoning during early childhood developed domain-specific anxiety as a result, producing the negative correlations between anxiety and performance that we observed. Therefore, longitudinal research on this topic will be required to understand the directionality of the reported anxiety-achievement relations and the degree to which these relations exhibit reciprocity across development.

In addition to the correlational nature of our study, the anxiety questionnaire developed for the present research also presented some limitations. Five scenarios were used to measure each of the three domain-specific anxieties assessed, which led to relatively low internal consistency for the three anxiety subscales ($\omega_s > .60$). Although similar reliability coefficients have been obtained in other studies administering brief math and spatial anxiety questionnaires to young children (Ramirez et al., 2012; Ramirez et al., 2013; Wong, 2017), questionnaires used to evaluate these types of anxiety in adulthood are often considerably longer, allowing for the more reliable measurement of individual differences. Given the objectives of our study, we limited the length of our anxiety measures so that we were able to evaluate three different forms of domain-specific anxiety in the same testing session without producing fatigue among our youngest participants. However, the development of a more comprehensive and reliable measure of domain-specific anxiety that is suitable for use

in young children will be necessary to directly address the continuity of anxiety-performance associations across development.

Implications

Previous research suggests that mathematical and spatial abilities during early childhood are predictive of later math achievement (Gunderson et al., 2012a; Lauer & Lourenco, 2016; Watts et al., 2014) and that gender differences in math and spatial reasoning abilities may contribute to gender differences in STEM achievement by early adolescence (Casey et al., 1995; Ganley et al., 2014; Wang et al., 2015). Yet, little research has investigated the affective correlates of children's math and spatial performance or gender differences therein. The results of the present study establish domain-specific anxiety as a unique predictor of children's performance on math and spatial measures, as well as gender differences in math and spatial anxiety across the elementary-school years. These findings call for further research aimed at identifying the various causal mechanisms underlying these individual and gender differences during childhood, which could not only further our theoretical knowledge of the developmental origins of these domain-specific anxieties but also expand our awareness of the various environmental and biological risk factors that predispose children to develop them. Furthermore, our results highlight the need for educational interventions designed to ameliorate math and spatial anxiety, particularly among girls, and suggest that such interventions may be optimally beneficial if introduced within the first years of formal schooling. Given the predictive role of early math and spatial reasoning abilities in later STEM achievement, such interventions would have the potential to improve young children's math and spatial performance and ultimately facilitate STEM success.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

- Ambady N, Shih M, Kim A, & Pittinsky TL (2001). Stereotype susceptibility in children: Effects of identity activation on quantitative performance. *Psychological Science*, 12(5), 385–390. doi: 10.1111/1467-9280.00371 [PubMed: 11554671]
- Ashcraft MH, & Krause JA (2007). Working memory, math performance, and math anxiety. *Psychonomic Bulletin & Review*, 14(2), 243–248. doi:10.3758/BF03194059 [PubMed: 17694908]
- Bander RS, & Betz NE (1981). The relationship of sex and sex role to trait and situationally specific anxiety types. *Journal of Research in Personality*, 15(3), 312–322. doi: 10.1016/0092-6566(81)90029-5
- Beilock SL, Rydell RJ, & McConnell AR (2007). Stereotype threat and working memory: mechanisms, alleviation, and spillover. *Journal of Experimental Psychology: General*, 136(2), 256–276. doi:10.1037/0096-3445.136.2.256 [PubMed: 17500650]

- Benbow CP, & Arjmand O (1990). Predictors of high academic achievement in mathematics and science by mathematically talented students: A longitudinal study. *Journal of Educational Psychology*, 82(3), 430–441. doi:10.1037/0022-0663.82.3.430
- Cardillo R, Vincenzi I, & Gallani A (2017). Spatial tasks and emotional factors: A study conducted with the Italian adaptation of the Child Spatial Anxiety Questionnaire (CSAQ). *Psicologia Clinica Dello Sviluppo*, 21(3), 483–502. doi:10.1449/88504
- Cargnelutti E, Tomasetto C, & Passolunghi MC (2017). How is anxiety related to math performance in young students? A longitudinal study of Grade 2 to Grade 3 children. *Cognition and Emotion*, 31(4), 755–764. doi:10.1080/02699931.2016.1147421 [PubMed: 26935005]
- Carroll JB (1993). *Human cognitive abilities: A survey of factor-analytic studies*. Cambridge, UK: Cambridge University Press.
- Casey MB, Nuttall R, Pezaris E, & Benbow CP (1995). The influence of spatial ability on gender differences in mathematics college entrance test scores across diverse samples. *Developmental Psychology*, 31(4), 697–705. doi:10.1037/0012-1649.31.4.697
- Casey BM, Pezaris E, Fineman B, Pollock A, Demers L, & Dearing E (2015). A longitudinal analysis of early spatial skills compared to arithmetic and verbal skills as predictors of fifth-grade girls' math reasoning. *Learning and Individual Differences*, 40, 90–100. doi:10.1016/j.lindif.2015.03.028
- Chipman SF, Krantz DH, & Silver R (1992). Mathematics anxiety and science careers among able college women. *Psychological Science*, 3(5), 292–296. doi:10.1111/j.1467-9280.1992.tb00675.x
- Curriculum Associates, (2017). *The science behind i-Ready's adaptive diagnostic*. Retrieved May 21, 2017 from <http://www.casamples.com/downloads/i-Ready-Diagnostic-Position-Paper.pdf>
- Cvencek D, Meltzoff AN, & Greenwald AG (2011). Math–gender stereotypes in elementary school children. *Child Development*, 82(3), 766–779. doi:10.1111/j.1467-8624.2010.01529.x [PubMed: 21410915]
- DeCaro MS, Rotar KE, Kendra MS, & Beilock SL (2010). Diagnosing and alleviating the impact of performance pressure on mathematical problem solving. *Quarterly Journal of Experimental Psychology*, 63(8), 1619–1630. doi:10.1080/17470210903474286
- Devine A, Fawcett K, Szűcs D, & Dowker A (2012). Gender differences in mathematics anxiety and the relation to mathematics performance while controlling for test anxiety. *Behavioral and Brain Functions*, 8(1), 33. doi:10.1186/1744-9081-8-33 [PubMed: 22769743]
- Dowker A, Sarkar A, & Looi CY (2016). Mathematics anxiety: What have we learned in 60 years?. *Frontiers in Psychology*, 7, 508. doi:10.3389/fpsyg.2016.00508 [PubMed: 27199789]
- Doyle RA, & Voyer D (2016). Stereotype manipulation effects on math and spatial test performance: A meta-analysis. *Learning and Individual Differences*, 47, 103–116. doi:10.1016/j.lindif.2015.12.018
- Eccles JS, & Jacobs JE (1986). Social forces shape math attitudes and performance. *Signs: Journal of Women in Culture and Society*, 11(2), 367–380. doi:10.1086/494229
- Ferguson AM, Maloney EA, Fugelsang J, & Risko EF (2015). On the relation between math and spatial ability: The case of math anxiety. *Learning and Individual Differences*, 39, 1–12. doi:10.1016/j.lindif.2015.02.007
- Ganley CM, & McGraw AL (2016). The development and validation of a revised version of the math anxiety scale for young children. *Frontiers in Psychology*, 7, 1181. doi:10.3389/fpsyg.2016.01181 [PubMed: 27605917]
- Ganley CM, Mingle LA, Ryan AM, Ryan K, Vasilyeva M, & Perry M (2013). An examination of stereotype threat effects on girls' mathematics performance. *Developmental Psychology*, 49(10), 1886–1897. doi:10.1037/a0031412 [PubMed: 23356523]
- Ganley CM, & Vasilyeva M (2014). The role of anxiety and working memory in gender differences in mathematics. *Journal of Educational Psychology*, 106(1), 105–120. doi:10.1037/a0034099
- Ganley CM, Vasilyeva M, & Dulaney A (2014). Spatial ability mediates the gender difference in middle school students' science performance. *Child Development*, 85(4), 1419–1432. doi:10.1111/cdev.12230 [PubMed: 24673201]
- Gunderson EA, Park D, Maloney EA, Beilock SL, & Levine SC (2018). Reciprocal relations among motivational frameworks, math anxiety, and math achievement in early elementary school. *Journal of Cognition and Development*, 19(1), 21–46. doi:10.1080/15248372.2017.1421538

- Gunderson EA, Ramirez G, Beilock SL, & Levine SC (2012a). The relation between spatial skill and early number knowledge: The role of the linear number line. *Developmental Psychology*, 48(5), 1229–1241. doi:10.1037/a0027433 [PubMed: 22390659]
- Gunderson EA, Ramirez G, Levine SC, & Beilock SL (2012b). The role of parents and teachers in the development of gender-related math attitudes. *Sex Roles*, 66, 153–166. doi:10.1007/s11199-011-9996-2
- Hegarty M, & Waller D (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence*, 32(2), 175–191. doi:10.1016/j.intell.2003.12.001
- Hembree R (1988). Correlates, causes, effects, and treatment of test anxiety. *Review of Educational Research*, 58(1), 47–77. doi:10.3102/00346543058001047
- Hembree R (1990). The nature, effects, and relief of mathematics anxiety. *Journal for Research in Mathematics Education*, 21(1), 33–46. doi:10.2307/749455
- Hill F, Mammarella IC, Devine A, Caviola S, Passolunghi MC, & Szűcs D (2016). Maths anxiety in primary and secondary school students: Gender differences, developmental changes and anxiety specificity. *Learning and Individual Differences*, 48, 45–53. doi:10.1016/j.lindif.2016.02.006
- Hyde JS, & Linn MC (1988). Gender differences in verbal ability: A meta-analysis. *Psychological Bulletin*, 104(1), 53–69. doi:10.1037/0033-2909.104.1.53
- Kazelskis R, Reeves C, Kersh ME, Bailey G, Cole K, Larmon M, ... & Holliday DC (2000). Mathematics anxiety and test anxiety: Separate constructs?. *The Journal of Experimental Education*, 68(2), 137–146. doi:10.1080/00220970009598499
- Kell HJ, Lubinski D, Benbow CP, & Steiger JH (2013). Creativity and technical innovation: Spatial ability's unique role. *Psychological Science*, 24(9), 1831–1836. doi:10.1177/0956797613478615 [PubMed: 23846718]
- Krinzinger H, Kaufmann L, & Willmes K (2009). Math anxiety and math ability in early primary school years. *Journal of Psychoeducational Assessment*, 27(3), 206–225. doi:10.1177/0734282908330583 [PubMed: 20401159]
- Lauer JE, & Lourenco SF (2016). Spatial processing in infancy predicts both spatial and mathematical aptitude in childhood. *Psychological Science*, 27(10), 1291–1298. doi:10.1177/0956797616655977 [PubMed: 27528464]
- Lawton CA (1994). Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. *Sex Roles*, 30(11–12), 765–779. doi:10.1007/BF01544230
- Lietz P (2006). A meta-analysis of gender differences in reading achievement at the secondary school level. *Studies in Educational Evaluation*, 32(4), 317–344. doi:10.1016/j.stueduc.2006.10.002
- Lyons IM, Ramirez G, Maloney EA, Rendina DN, Levine SC, & Beilock SL (in press). Spatial Anxiety: A novel questionnaire with subscales for measuring three aspects of spatial anxiety. *Journal of Numerical Cognition*.
- Ma X (1999). A meta-analysis of the relationship between anxiety toward mathematics and achievement in mathematics. *Journal for Research in Mathematics Education*, 30(5), 520–540. doi:10.2307/749772
- Malanchini M, Rimfeld K, Shakeshaft NG, Rodic M, Schofield K, Selzam S, ... & Kovas Y (2017). The genetic and environmental aetiology of spatial, mathematics and general anxiety. *Scientific Reports*, 7, 42218. doi:10.1038/srep42218 [PubMed: 28220830]
- Maloney EA, Waechter S, Risko EF, & Fugelsang JA (2012). Reducing the sex difference in math anxiety: The role of spatial processing ability. *Learning and Individual Differences*, 22(3), 380–384. doi:10.1016/j.lindif.2012.01.001
- Miller H, & Bichsel J (2004). Anxiety, working memory, gender, and math performance. *Personality and Individual Differences*, 37(3), 591–606. doi:10.1016/j.paid.2003.09.029
- Moè A (2018). Mental rotation and mathematics: Gender-stereotyped beliefs and relationships in primary school children. *Learning and Individual Differences*, 61, 172–180. doi:10.1016/j.lindif.2017.12.002
- Mueller ST, & Piper BJ (2014). The psychology experiment building language (PEBL) and PEBL test battery. *Journal of Neuroscience Methods*, 222, 250–259. doi:10.1016/j.jneumeth.2013.10.024 [PubMed: 24269254]

- Muzzatti B, & Agnoli F (2007). Gender and mathematics: Attitudes and stereotype threat susceptibility in Italian children. *Developmental Psychology*, 43(3), 747–759. doi:10.1037/0012-1649.43.3.747 [PubMed: 17484585]
- Neuburger S, Ruthsatz V, Jansen P, & Quaiser-Pohl C (2015). Can girls think spatially? Influence of implicit gender stereotype activation and rotational axis on fourth graders' mental-rotation performance. *Learning and Individual Differences*, 37, 169–175. doi:10.1016/j.lindif.2014.09.003
- Osborne JW (2001). Testing stereotype threat: Does anxiety explain race and sex differences in achievement?. *Contemporary Educational Psychology*, 26(3), 291–310. doi:10.1006/ceps.2000.1052 [PubMed: 11414722]
- Passolunghi MC, Ferreira TIR, & Tomasetto C (2014). Math–gender stereotypes and math-related beliefs in childhood and early adolescence. *Learning and Individual Differences*, 34, 70–76. doi:10.1016/j.lindif.2014.05.005
- Ramirez G, Chang H, Maloney EA, Levine SC, & Beilock SL (2016). On the relationship between math anxiety and math achievement in early elementary school: The role of problem solving strategies. *Journal of Experimental Child Psychology*, 141, 83–100. doi:10.1016/j.jecp.2015.07.014 [PubMed: 26342473]
- Ramirez G, Gunderson EA, Levine SC, & Beilock SL (2012). Spatial anxiety relates to spatial abilities as a function of working memory in children. *The Quarterly Journal of Experimental Psychology*, 65(3), 474–487. doi:10.1080/17470218.2011.616214 [PubMed: 22239255]
- Ramirez G, Gunderson EA, Levine SC, & Beilock SL (2013). Math anxiety, working memory, and math achievement in early elementary school. *Journal of Cognition and Development*, 14(2), 187–202. doi:10.1080/15248372.2012.664593
- Scholastic Reading Inventory. (1999). New York, NY: Scholastic, Inc.
- Thurstone TG, & Thurstone LL (1974). PMA readiness level. Chicago, IL: Science Research Associates.
- Tomasetto C, Alparone FR, & Cadinu M (2011). Girls' math performance under stereotype threat: The moderating role of mothers' gender stereotypes. *Developmental Psychology*, 47(4), 943–949. doi:10.1037/a0024047. [PubMed: 21744956]
- Voyer D, Voyer S, & Bryden MP (1995). Magnitude of sex differences in spatial abilities: a meta-analysis and consideration of critical variables. *Psychological Bulletin*, 117(2), 250–270. doi:10.1037/0033-2909.117.2.250 [PubMed: 7724690]
- Vukovic RK, Kieffer MJ, Bailey SP, & Harari RR (2013). Mathematics anxiety in young children: Concurrent and longitudinal associations with mathematical performance. *Contemporary Educational Psychology*, 38(1), 1–10. doi:10.1016/j.cedpsych.2012.09.001
- Wai J, Lubinski D, & Benbow CP (2005). Creativity and occupational accomplishments among intellectually precocious youths: An age 13 to age 33 longitudinal study. *Journal of Educational Psychology*, 97(3), 484–492. doi:10.1037/0022-0663.97.3.484
- Wai J, Lubinski D, & Benbow CP (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, 101(4), 817–835. doi:10.1037/a0016127
- Wang L, Cohen AS, & Carr M (2014). Spatial ability at two scales of representation: A meta-analysis. *Learning and Individual Differences*, 36, 140–144. doi:10.1016/j.lindif.2014.10.006
- Wang MT, Degol J, & Ye F (2015). Math achievement is important, but task values are critical, too: Examining the intellectual and motivational factors leading to gender disparities in STEM careers. *Frontiers in Psychology*, 6, 36. doi:10.3389/fpsyg.2015.00036 [PubMed: 25741292]
- Wang Z, Hart SA, Kovas Y, Lukowski S, Soden B, Thompson LA, ... & Petrill SA (2014). Who is afraid of math? Two sources of genetic variance for mathematical anxiety. *Journal of Child Psychology and Psychiatry*, 55(9), 1056–1064. doi:10.1111/jcpp.1222 [PubMed: 24611799]
- Watts TW, Duncan GJ, Siegler RS, & Davis-Kean PE (2014). What's past is prologue: Relations between early mathematics knowledge and high school achievement. *Educational Researcher*, 43(7), 352–360. doi:10.3102/0013189X14553660 [PubMed: 26806961]
- Wong WI (2017). The space-math link in preschool boys and girls: Importance of mental transformation, targeting accuracy, and spatial anxiety. *British Journal of Developmental Psychology*, 35(2), 249–266. doi:10.1111/bjdp.12161 [PubMed: 27761929]

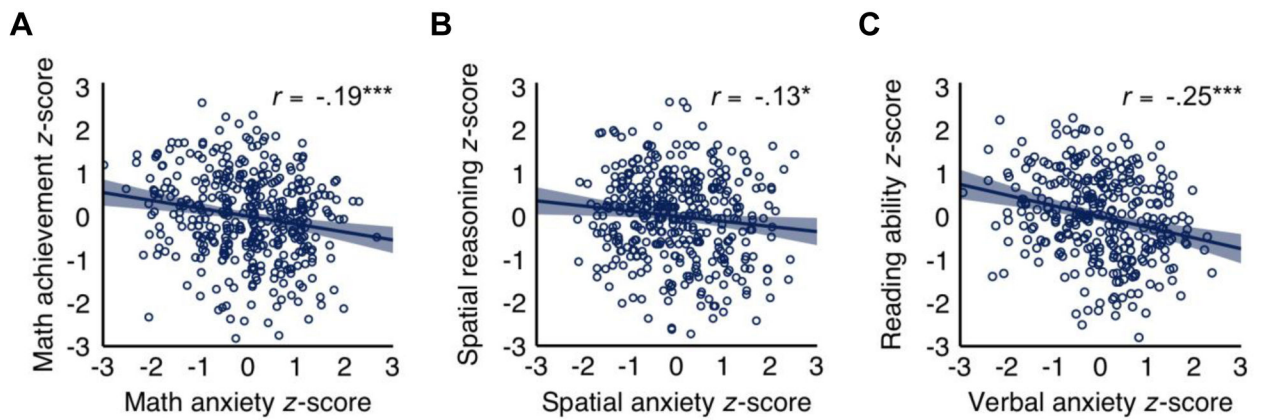


Figure 1.

Scatterplots depicting zero-order correlations between anxiety and performance by domain. (A) Greater math anxiety was associated with lower math achievement: $r(392) = -.19$, 95% CI $[-.28, -.09]$, $p < .001$. (B) Greater spatial anxiety was associated with poorer spatial reasoning performance: $r(392) = -.13$, 95% CI $[-.22, -.03]$, $p = .010$. (C) Greater verbal anxiety was associated with lower reading ability: $r(314) = -.25$, 95% CI $[-.35, -.14]$, $p < .001$. The shaded regions represent the 95% confidence intervals of each regression line. See Figure S1 for partial regression plots displaying anxiety-performance relations within each domain when controlling for children's anxiety in other domains.

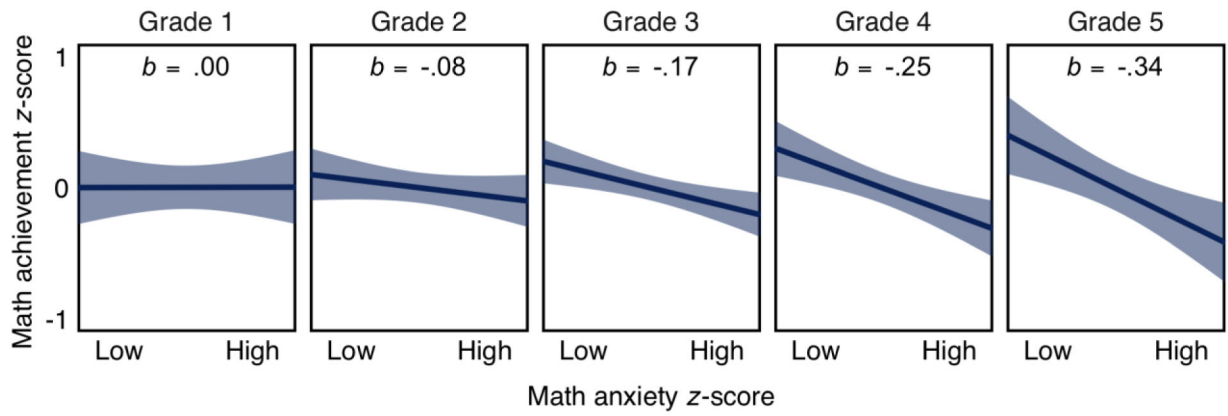


Figure 2.

Simple slopes plots illustrating the moderating effect of grade on the relation between math anxiety and math achievement. Math anxiety is plotted at 1 standard deviation below the mean (*low*) and at 1 standard deviation above the mean (*high*).

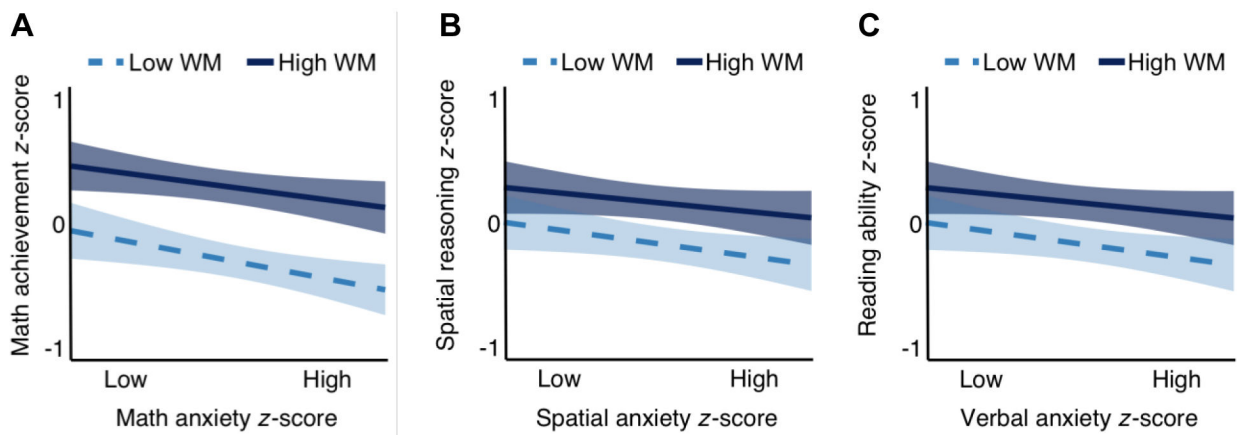


Figure 3.

Simple slopes plots displaying the relations between (A) math anxiety and math achievement, (B) spatial anxiety and spatial reasoning performance, and (C) verbal anxiety and reading ability as a function of working memory (WM). Anxiety *z*-scores and working memory *z*-scores are plotted at 1 standard deviation below the mean (*low*) and at 1 standard deviation above the mean (*high*). Working memory did not significantly moderate the relation between anxiety and performance for any domain assessed.

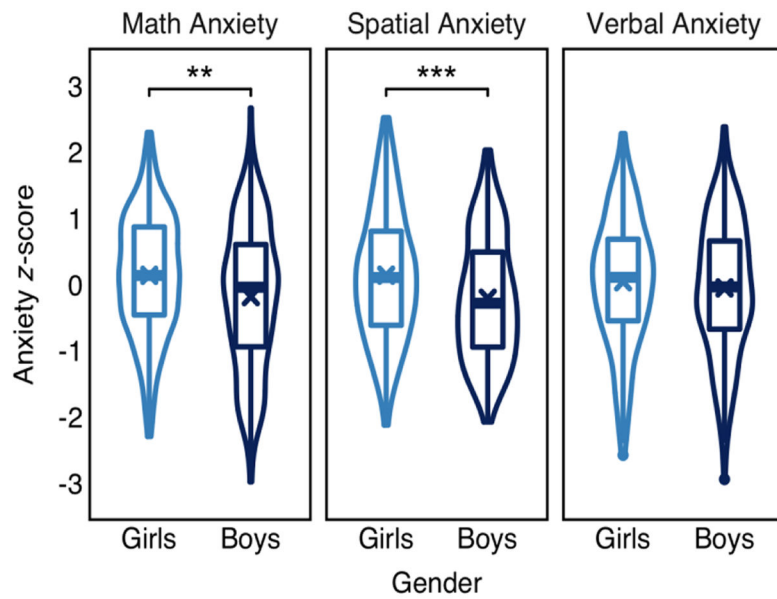


Figure 4.

Violin plots with inner boxplots depicting gender differences in children's self-reported anxiety by cognitive domain. Crosses denote mean anxiety z-scores. Girls reported experiencing significantly greater math anxiety ($d = 0.33$, $p = .001$) and spatial anxiety ($d = 0.37$, $p < .001$) relative to boys, but there was no gender difference in children's verbal anxiety ($d = 0.09$, $p = .366$).

** $p < .01$, *** $p < .001$

Table 1

Sample Size and Mean Age of Participants in Years by Grade Level and Gender

Grade	All		Female		Male	
	<i>N</i>	<i>M (SD)</i>	<i>N</i>	<i>M (SD)</i>	<i>N</i>	<i>M (SD)</i>
1	78	7.01 (0.32)	37	6.98 (0.27)	41	7.04 (0.37)
2	85	7.97 (0.40)	50	7.95 (0.43)	35	8.01 (0.35)
3	81	9.23 (0.36)	47	9.23 (0.36)	34	9.23 (0.37)
4	73	10.12 (0.46)	48	10.11 (0.50)	25	10.16 (0.39)
5	77	11.13 (0.36)	45	11.08 (0.34)	32	11.21 (0.38)

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Table 2

Correlations Between Anxiety and Performance Across Domains

Measure	1	2	3	4	5	6	7
1. Math anxiety	-	.39***	.44***	-.19***	-.13**	-.17**	-.08
2. Spatial anxiety		-	.37***	-.05	-.13*	-.07	-.03
3. Verbal anxiety			-	-.20***	-.11*	-.25***	-.02
4. Math achievement				-	.33***	.62***	.31***
5. Spatial reasoning					-	.22***	.17***
6. Reading ability						-	.24***
7. Working memory							-

Note. For correlations with reading ability, $N = 316$. For all other correlations, $N = 394$.

*
 $p < .05$

**
 $p < .01$

 $p < .001$

Table 3

Results of Multiple Regression Analyses Predicting Math Achievement (N = 394)

Unique Predictor	β	t	p	F	df	p	adj. R^2
<i>Model 1</i>				4.68	5, 388	<.001	.04
Gender	.03	0.50	.615				
Grade	.00	-0.04	.967				
Math anxiety	-.15	-2.61	.009				
Spatial anxiety	.07	1.19	.234				
Verbal anxiety	-.16	-2.79	.006				
<i>Model 2</i>				3.88	8, 385	<.001	.06
Math anxiety \times grade	-.28	-2.10	.037				
Spatial anxiety \times grade	.22	1.77	.078				
Verbal anxiety \times grade	.16	1.24	.215				

Note. Gender coded as female: +1, male: -1.

Table 4

Results of Multiple Regression Analyses Predicting Spatial Reasoning Performance (N = 394)

Unique Predictor	β	t	p	F	df	p	adj. R^2
<i>Model 1</i>				2.11	5, 388	.064	.01
Gender	.01	0.13	.897				
Grade	.00	-0.01	.991				
Math anxiety	-.08	-1.42	.155				
Spatial anxiety	-.08	-1.44	.151				
Verbal anxiety	-.04	-0.78	.436				
<i>Model 2</i>				1.32	8, 385	.231	.01
Math anxiety \times grade	-.04	-0.33	.743				
Spatial anxiety \times grade	.01	0.09	.929				
Verbal anxiety \times grade	.01	0.06	.951				

Note. Gender coded as female: +1, male: -1.

Table 5

Results of Multiple Regression Analyses Predicting Reading Ability (N = 316)

Unique Predictor	β	t	p	F	df	p	adj. R^2
<i>Model 1</i>				4.52	5, 310	<.001	.05
Gender	.00	0.05	.961				
Grade	.00	0.00	.999				
Math anxiety	-.09	-1.33	.186				
Spatial anxiety	.06	0.94	.346				
Verbal anxiety	-.23	-3.65	<.001				
<i>Model 2</i>				3.11	8, 307	.002	.05
Math anxiety \times grade	-.29	-1.39	.166				
Spatial anxiety \times grade	.06	0.32	.752				
Verbal anxiety \times grade	.00	0.02	.982				

Note. Gender coded as female: +1, male: -1.