Current Psychology (2024) 43:1381–1394
https://doi.org/10.1007/s12144-023-04349-y

Math anxiety is more closely associated with math performance in female students than in male students

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Accepted: 30 January 2023 / Published online: 23 February 2023

Abstract

Objective: Math anxiety has been shown to correlate negatively with math performance among students. It remains unclear whether this relationship differs between boys and girls. The current study aimed to examine gender differences in the link between math anxiety and math achievement in elementary and secondary school students. **Methods:** All students involved in the study (17,382 fourth-grade students and 11,346 eighth-grade students) completed a math-anxiety questionnaire and several math-achievement tests. **Results:** Math anxiety and math achievement were negatively correlated in both boys and girls. The moderating effect of gender on this correlation was significant, and the correlation was stronger in girls than in boys, regardless of grade. **Conclusion:** The link between math anxiety and math achievement is stronger for girls than for boys, which suggests we should pay more attention to how girls react emotionally to math.

Keywords Math anxiety · Math achievement · Gender difference

Introduction

Math anxiety—a state of fear and tension toward math (Ashcraft, 2002; Ashcraft & Ridley, 2005)—has long been a concern in education. It was a stable and independent psychological construct separate from other social-emotional attitudes (Cheng et al., 2022). A series of studies has shown that math anxiety is a common problem that can be found from elementary school through college. The negative association between math anxiety and math achievement (Ashcraft, 2002; Barroso et al., 2021; Ma, 1999; Ma & Xu, 2004; Namkung et al., 2019; Rodarte Luna & Sherry, 2008; Zhang et al., 2019) is separate from effects related to general anxiety disorder (Cargnelutti, Tomasetto, & Passolunghi., 2017; Hill et al., 2016). Although numerous studies have investigated gender differences in either math anxiety or math achievement (e.g., Chang & Cho, 2013; Punaro & Reeve, 2012; Gunderson et al., 2013; Young et al., 2012), few have explored whether the relationship between the two differs between males and females.

Studies have shown gender differences in emotional susceptibility (Mak et al., 2009; Ebisch et al., 2015; Yang et al., 2018; Yuan et al., 2010, 2021), which refers to an individual's ability to feel an emotion and the degree to which cognitive processes are affected by emotion (Rusting & Larsen, 1997; Zelenski & Larsen, 1999). Studies have reported that

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females are more sensitive to negative emotions and more negatively affected by them (Gard & Kring, 2007; Li et al., 2008; Yang et al., 2018; Yuan et al., 2010, 2021). Yuan et al. (2010) used two target-free oddball tasks and found that even if the oddball stimuli did not contain any emotional content, as long as there was a sudden impact, females reacted with a stronger shock response than males. Based on this, we propose a gender-difference hypothesis for the math anxiety-achievement link, and the link might be stronger among girls than among boys. In this study, we used a large sample size (28,129 primary and secondary school students) and multiple math-achievement tests to verify the consistency and stability of the conclusion.

Math anxiety and math achievement

Consistent evidence has suggested that the math anxiety-achievement link is a general and global phenomenon across different ages, races, and countries. The results from five meta-analysis studies (Barroso et al., 2021; Hembree, 1990; Ma, 1999; Namkung et al., 2019; Zhang et al., 2019) showed that math anxiety is moderately and negatively associated with math achievement (i.e., $r = -.28$ in Barroso et al., 2021; $r = -.34$ in Hembree 1990; $r = -.27$ in Ma 1999; $r = -.34$ in Namkung et al., 2019; $r = -.30$ in Zhang et al., 2019). For example, including 131 studies with 478 effect sizes, Namkung et al. (2019) found that math anxiety was associated with poorer math achievement among school-aged students (primary school to high school). Moreover, data from the Program for International Student Assessment (PISA) showed a negative association between math anxiety and math achievement globally generalizable across 63 of the 64 investigated education systems (Foley et al., 2017). In addition to cross-sectional studies, significant math anxiety-achievement links have also been reported in longitudinal studies (Ashcraft & Moore, 2009; Carey et al., 2017; Cargnelutti et al., 2017; Ma & Xu, 2004). Cargnelutti et al. (2017) designed a longitudinal study to define the early association between math anxiety and math performance in Grades 2 and 3. The study examined 198 Grade 2 students in Northeastern Italy, among whom 80 participated in the second phase in Grade 3. Results showed a strong negative relationship between math anxiety and achievement in Grades 2 and 3. Longitudinal analyses also showed an indirect effect of math anxiety in Grade 2 on subsequent math performance in Grade 3.

Gender differences in math anxiety

Although gender differences in math anxiety have been studied extensively, conclusions have been inconsistent. First, several studies have found that boys have higher levels of math anxiety than girls (Abed & Alkhateeb, 2001; Olmez & Ozel, 2012). Abed and Alkhateeb (2001) recruited 159 urban and rural Arabic-speaking students in Grade 8 and found that boys reported higher math anxiety scores than girls. The United Arab Emirates public school system is separated by gender from Grades 1 through 12. Olemez and Ozel (2012) found that the level of math anxiety was related to the degree of appreciation for the math teacher; students who liked their teacher had lower anxiety levels. Girls were more likely to notice the care and support provided by their teachers and express their negative academic emotions to their teachers more effectively than boys (Lei et al., 2018).

Second, in most countries or regions, female levels of math anxiety appear to be higher than male levels. The meta-analyses' results suggest that girls' math anxiety levels are significantly higher than boys' (Else-Quest et al., 2010; Hembree, 1990). Studies have shown that females report higher levels of math anxiety than males across different countries and grades (e.g., Devine et al., 2012; Hart & Ganley, 2019; Hill et al., 2016; Yüksel-Şahin, 2008). Frenzel et al. (2007) found that the gender difference could be attributed to different emotions. For example, girls reported experiencing less enjoyment and pride than boys in mathematics, which led girls to have low self-confidence in math. Beilock et al. (2010) found that negative social stereotypes are detrimental to math performance in girls and increase their math anxiety.

Third, other studies have shown that typical gender differences in math anxiety were absent (Amam et al., 2019; Keshavarzi & Ahmadi, 2013; Ma, 1999; Srivastava et al., 2016). The PISA2012 survey results indicated that gender differences in math anxiety depended on the region. In some countries, such as Albania, Bulgaria, Indonesia, Kazakhstan, Malaysia, Montenegro, Romania, Serbia, and Turkey, math anxiety did not significantly differ by gender (OECD, 2015). Keshavarzi and Ahmadi (2013) found no significant differences in math anxiety between boys and girls among 834 high school students in Iran. They thought cultural values concerning female success in mathematics and related fields had altered and that females are now more interested in math and have an increasing influence in math and engineering fields. Thus, females might have more self-confidence and less anxiety in math, which may narrow the gender differences in math anxiety.

Gender differences in the link between math anxiety and math achievement

The association between math anxiety and math achievement could differ between male and female students, irrespective of the level of anxiety or achievement. As recounted above, numerous experiments have focused

Table 1 Results for gender-difference tests in ten samples of math anxiety vs. achievement correlations

Publication	Total	Boy	Correlation coefficient(*r*)	Girl	Correlation coefficient(*r*)	*p*	Cohen's *q*
Erturan & Jansen, 2015	134	73	−0.15	61	−0.37	0.091	0.237
Devine et al., 2012	433	268	−0.18	165	−0.35	0.033	0.183
Reali et al., 2016	296	136	0.08	160	0.24	0.081	0.165
Mier et al., 2019	62	31	0.09	31	−0.41	0.025	0.526
	62	26	−0.04	36	−0.55	0.017	0.578
Hill et al., 2016	639	317	−0.07	322	−0.13	0.223	-
	342	194	−0.28	148	−0.34	0.273	-
Olmez & Ozel, 2012	244	128	−0.37	116	−0.58	0.017	0.274
Caube et al., 2019	292	143	−0.39	149	−0.28	0.304	-
Geary et al., 2019	1097	545	−0.05	546	−0.19	0.010	0.142

Notes: p is the p-value for the difference test that we calculated. Five papers reported the results of difference tests: Erturan and Jansen (2015) reported $p < .001$; Devine et al. (2012) reported $p = .03$; Reali et al. (2016) reported $p = .11$; Mier et al. (2019) reported $p = .007$; Geary et al., 2019 reported $p = .010$

on gender differences in math anxiety, but relatively few have explored whether the math anxiety-achievement link depends on gender. Furthermore, the limited evidence so far has also been mixed. For example, Geary et al. (2019) found that girls with low math achievement were more likely to have math anxiety than boys with low math achievement. In contrast, two recent meta-analyses reported no significant differences between females and males in the math anxiety-achievement link (Barroso et al., 2021; Zhang et al., 2019). Barroso et al. (2021) analyzed gender differences with samples of only male and female participants. Samples with mixed gender were not included in the meta-analysis. In Zhang et al. (2019), only 5 of the 49 studies in the meta-analysis investigated gender differences in the math anxiety-achievement link; the others all reported the link based on mixed gender samples.

Based on two recent meta-analyses, we obtained eight empirical studies on gender differences in the math anxiety-achievement link. Only five of the eight studies (ten samples, Hill et al., 2016 and Mier et al., 2019 have two samples each) conducted statistical tests on gender differences. For standardization, we conducted statistical tests according to the statistical values reported in these studies. We used a statistical test on the eight studies to compare correlations from independent samples (Calculation according to Eid et al., 2011, S. 548 f.; single-sided testing). This method uses the number of male and female students reported in the research and the correlation coefficient provided by a gender test. Significant gender differences were found in five samples, four at the 0.05 level and one at the 0.01 level. The effect sizes for the former were 0.183 (Devine et al., 2012), 0.274 (Olmez & Ozel, 2012), 0.526, and 0.578 (Mier et al., 2019), while that for the latter was 0.142 (Geary et al., 2019). Differences were marginally significant in two samples ($p = .091$ in Erturan & Jansen, 2015; and $p = .081$ in Reali et al., 2016), with effect sizes being 0.237 (Erturan & Jansen, 2015) and 0.165 (Reali et al., 2016). No significant gender differences were found in three of the samples (Hill et al., 2016; Caube et al., 2019). The inconsistent findings could be due to the small sample sizes in these studies, which ranged from just 62 to 1097 children, with 360 participants per study on average (see Table 1 for detailed results, the original results of the five studies were shown in the table notes).

Current study

The goal of the current study was to determine whether the math anxiety-achievement link depends on gender. We put forward a hypothesis: there is a gender difference, and it would take the form of a stronger negative association between math anxiety and math achievement in girls than in boys.

The rationale for this hypothesis is related to reported gender differences in emotional susceptibility (Mak et al., 2009; Ebisch et al., 2015; Yuan et al., 2010, 2021). Emotional susceptibility refers to an individual's ability to feel an emotion and the degree to which cognitive processes are affected by emotion (Rusting & Larsen, 1997; Zelenski & Larsen, 1999). On the one hand, some research has found that females are more sensitive to negative emotions and are more negatively affected by them, while males are calmer and less vulnerable to negative emotions (Gard & Kring, 2007; Koch et al., 2007; McRae et al., 2008; Mak et al., 2009; Li et al., 2008; Yang et al., 2018; Yuan et al., 2010; Yuan et al., 2021). For example, Yuan et al. (2021) found that females were a more enhanced susceptibility to emotional stimuli than males. Furthermore, this gender difference was mainly manifested by women's high sensitivity to negative stimuli. Meanwhile, negative stimuli can also cause negative emotions, such as anxiety. Yang et al. (2018) summarized three aspects of the emotion-related gender differences: attention allocation, cognitive evaluation, and late emotional arousal/experiences. Females tend to allocate more attentional resources to negative stimuli (Yuan et al., 2009), give a more negative evaluation to ambiguous emotional pictures (Krohne & Hock, 2008), and are more likely to arouse negative emotions through negative film clips than males (Maffei et al., 2015). On the other hand, evidence from neuroimaging showed different emotional processing modes among females and males. For example, Koch et al. (2007) found that during the cognitive control of emotion, females primarily recruited emotion-related areas of the brain (the amygdala and the OFC), while males primarily recruited brain regions important for other types of cognitive processing (the prefrontal and superior parietal regions). Mak et al. (2009) used functional magnetic resonance imaging (fMRI) to study gender-related differences in neural activity during emotion regulation and found gender-specific sets of brain regions involved in regulating negative emotion. In their fMRI study, females had more difficulty regulating negative emotions than males. Males showed more activation in the prefrontal regions, including the left dorsolateral and lateral orbitofrontal gyri, as well as the right anterior cingulate gyrus, which has been implicated in cognitive processes such as working memory (Miller & Cohen, 2001) and higher-order cognitive functions that include selecting and shifting between abstract rules (Zelazo & Cunningham, 2006). In one study, compared to males, females only showed stronger activation in the left medial orbitofrontal gyrus, which has been implicated in affective processing such as empathy (Shamay-Tsoory et al., 2003). The post-scan analysis of the strategies used by males and females during the experiment showed that when regulating emotion, females were more likely than males to use the strategy of emotional focus—immersing themselves in negative emotion—indicating that their cognitive processes are more easily affected by emotion. In contrast, males were more likely to use cognitive restructuring strategies to eliminate negative emotions. Based on the above studies, we can infer that when encountering negative emotions such as math anxiety in solving math problems, boys are more likely to realize the shift between emotions and cognition, enabling them to use more rational and detached coping strategies. In contrast, girls might be more likely to become immersed in affective processing and have a more difficult time transferring attention to cognitive tasks.

In the current study, we tested our hypothesis in a large sample of 28,129 primary and secondary school students recruited from 489 elementary and 238 junior high schools. This investigation was part of a broader project to monitor education quality in Qingdao, China. We divided fourth- and eighth-grade math problems into twelve sets of equally difficult parallel test papers (six per grade). On average, each test was taken by 2,344 students. This process was done to verify the consistency of the conclusions.

Methods

Participants

Our study used data from monitoring education quality in the Chinese city of Qingdao (Shandong Province), conducted via random cluster sampling. Qingdao is the vice-provincial capital city of Shandong Province, the second most populous province in China (data from China Statistical Yearbook 2021). It is a typical representative of eastern cities in China. A total of 17,382 fourth graders and 11,346 eighth graders were selected, representing 17.7% and 12.8% of the total number of fourth and eighth graders in Qingdao, respectively. Grades 4 and 8 were selected according to the National Compulsory Education Quality Monitoring Plan, which suggests that the fourth and eighth grades represent the intermediate stages of primary and junior high school, respectively. The fourth- and eighth-grade students were frequently investigated in the existing studies, which was convenient for comparison.

The data used in the current study were collected in May 2018. Children were recruited from 489 elementary schools and 238 junior high schools. Parental consent was obtained prior to classroom-based testing. Among the 28,728 individuals in the original sample, data from 554 were dropped because math anxiety or math test data was missing, and 43 were dropped due to errors in filling out the gender, schooling style, or age. Thus, this final sample that was analyzed included 28,129 participants, of which 17,096 were fourth-grade students (8,838 males, 8,258 females, mean age = 9.8 ± 0.43 years) and 11,033 were eighth-grade students (5,432 males, 5,601 females, mean age = 13.7 ± 0.53 years).

Detailed demographic information is shown in Table 2.

Measurements

Math anxiety

Math anxiety was measured using a revised version of the Abbreviated Math Anxiety Rating Scale (Alexander & Martray, 1989), a ten-item self-report survey on a five-point Likert scale. Students responded to questions about how anxious they would feel during different situations (1 = not at all anxious, two = a little anxious, 3 = fairly anxious, 4 = very anxious, 5 = extremely anxious). Scores were summed across the ten questions to generate the final score. This scale had

Table 2 Sample size by gender, grade level, and test version

	Grade 4			Grade 8	
	Number (Male, Female)	Mean age, years (Male, Female)		Number (Male, Female)	Mean age, years (Male, Female)
Test 1	2,856 (1,458, 1,398)	9.79 (9.81, 9.77)	**Test 1**	1,837 (945, 892)	13.66 (13.69, 13.64)
Test 2	2,848 (1,426, 1,422)	9.79 (9.79, 9.80)	**Test 2**	1,843 (898, 945)	13.64 (13.66, 13.61)
Test 3	2,853 (1,460, 1,393)	9.79 (9.79, 9.80)	**Test 3**	1,826 (903, 923)	13.66 (13.68, 13.63)
Test 4	2,850 (1,486, 1,364)	9.79 (9.80, 9.78)	**Test 4**	1,841 (882, 959)	13.66 (13.70, 13.62)
Test 5	2,852 (1,488, 1,364)	9.8 (9.81, 9.80)	**Test 5**	1,845 (887, 958)	13.66 (13.69, 13.63)
Test 6	2,837 (1,520, 1,317)	9.81 (9.82, 9.79)	**Test 6**	1,841 (917, 924)	13.64 (13.69, 13.59)
Total	17,096 (8,838, 8,258)	9.8 (9.80, 9.79)	**Total**	11,033 (5,432, 5,601)	13.65 (13.69, 13.62)

excellent internal consistency, with Cronbach's alphas of 0.903 and 0.925 for Grades 4 and 8, respectively.

Math performance

The math achievement test was based on curriculum standards in China and drew on the experience of large-scale tests in international math disciplines. To evaluate fourth and eighth-grade math achievement, we compiled a table of specifications in terms of content (knowledge in the curriculum) and cognitive dimension (knowledge, understanding, mastering, and application). To ensure the accuracy of the test of education quality, the content of the math achievement test covered the 'knowledge' aspects of the standard curriculum as much as possible. According to the content and types of knowledge, we compiled six sets of test papers for each of the two grades. The six sets of test papers had precisely the same type and quantity of questions. The knowledge points examined were similar, while the specific questions were different. These 12 tests (six per grade) had excellent internal consistency, with all Cronbach's alphas above 0.8. One of the six sets of test papers was randomly assigned to each school. The number of students tested by each set of test papers was the same (Table 2).

Each set of papers had three questions: multiple-choice, fill-in-the-blank, and free answers. All multiple-choice problems had four choices, of which one was correct. Answers were scored as 0 (incorrect) or 1 (correct). The fill-in-the-blanks also were scored as 0 (incorrect) or 1 (correct). The free-answer problems required students to list the steps they used to obtain their answers. Scores ranged from 0 to 21 for Grade 4 and from 0 to 24 for Grade 8. Each fourth-grade test contained 16 multiple-choice problems, 12 fill-in-the-blank problems with one or two blanks, and four free-answer problems. The full test scores of Tests 1 to 6 were 51, 62, 62, 49, 57, and 55, respectively. Each eighth-grade test contained 12 multiple-choice problems, four fill-in-the-blank problems with one or two blanks, and three free-answer questions. The full test score of Tests 1 to 6 were 34, 30, 28, 41, 38, and 30, respectively.

Procedure

Participants first took a computerized math-anxiety test in a computer room, followed by a paper-based math-achievement test in the classroom. This order was chosen to avoid the possibility that imagined success/failure on the math-achievement test would influence answers on the math-anxiety task. The math-anxiety test had no time limit, and all students completed it within 30 min. The math-achievement test was limited to 60 min. To minimize the influence of time pressure, we set the limit to 60 min after comprehensively considering the number of questions for math achievement tests, our pilot test, and previous testing standards. Most students were able to complete the test within this time. During the test, each class was monitored by two experimenters. All students received the same instructions and started at the same time.

Data analysis

Our main interest was to examine how the relationship between math anxiety and math achievement differed depending on gender. First, we conducted a difference contrast between math anxiety and math achievement. Multi-factor analysis of variance was conducted with math anxiety and math achievement as the dependent variables and gender (male or female), Test Version (1–12), and Grade (4 or

Table 3 Means and standard deviations for math anxiety and math achievement

		Math anxiety		Math achievement	
		Boys	Girls	Boys	Girls
Grade 4	Test 1	34.68(11.07)	32.71(10.92)	32.66(9.72)	32.18(9.03)
	Test 2	35.18(11.23)	33.12(11.21)	40.17(11.12)	40.52(10.07)
	Test 3	34.76(11.25)	32.54(11.00)	35.63(10.50)	36.32(9.65)
	Test 4	34.78(11.09)	32.95(11.26)	28.76(9.40)	28.76(8.21)
	Test 5	34.21(11.19)	32.91(11.17)	36.66(11.21)	36.46(10.37)
	Test 6	34.36(11.25)	32.39(11.29)	33.43(9.99)	32.66(9.42)
	Total	34.66(11.18)	32.77(11.14)	34.51(10.93)	34.53(10.21)
Grade 8	Test 1	28.16(11.85)	26.57(10.79)	18.00(8.22)	18.35(7.48)
	Test 2	28.93(12.02)	26.83(11.16)	16.67(6.56)	16.92(6.42)
	Test 3	28.63(11.90)	26.52(10.79)	13.62(6.83)	13.72(6.26)
	Test 4	29.32(11.65)	26.56(10.76)	19.66(9.11)	20.19(8.09)
	Test 5	28.57(11.81)	26.88(10.68)	20.50(9.63)	20.36(8.94)
	Test 6	28.70(11.94)	26.49(10.50)	16.12(7.82)	16.11(7.48)
	Total	28.71(11.86)	26.64(10.78)	17.41(8.41)	17.63(7.86)

8) as independent variables. We thus tested whether gender differences in math anxiety were consistent across different test versions and grades. Then, we analyzed the correlation between math anxiety and math achievement in the two grades. The moderating effect was assessed to examine how the relationship between math anxiety and math achievement differed depending on gender. Considering that a large sample of students from 489 elementary schools and 238 junior high schools were used in this study, we needed to determine whether or not the nested data should be analyzed with multilevel models. We first specified a null model to compute the intraclass correlation coefficients (ICC). The ICC of math achievement was 0.17 for all students, suggesting significant between-school variability. Therefore, we conducted random coefficient modeling using the MIXED procedure in SPSS for all analyses. Continuous variables were first centralized. Math-anxiety scores were standardized, and math-achievement scores for the six tests were standardized separately. The equation for the student-level analysis was:

$$
\begin{aligned}
math_{ij} = \beta_{0j} + \beta_{1j}(gender)_{ij} + \beta_{2j}(MA)_{ij} + \beta_{3j}(gender \times MA)_{ij} \\
+ \beta_{4j}(grade)_{ij} + \beta_{5j}(grade \times MA)_{ij} \\
+ \beta_{6j}(grade \times gender \times MA)_{ij} + e_{ij}
\end{aligned}
$$

In this equation, $math_{ij}$ is the math achievement for student i in school j, and β_{0j} is the mean score for school j. β_{1j}, β_{2j}, β_{3j}, β_{4j}, β_{5j}, and β_{6j} are the slopes for gender, MA(math anxiety), the interaction between gender and math anxiety, grade, the interaction between grade and math anxiety, and the interaction between grade, gender, and math anxiety predicting the math achievement in school j. e_{ij} is the random component of the score for student i in school j.

The equations for the school-level analysis were:

$$
\begin{aligned}
\beta 0j &= \gamma 00 + \mu 0j \\
\beta 1j &= \gamma 10 + \mu 1j \\
\beta 2j &= \gamma 20 + \mu 2j \\
\beta 3j &= \gamma 30 \\
\beta 4j &= \gamma 40 \\
\beta 5j &= \gamma 50 \\
\beta 6j &= \gamma 60
\end{aligned}
$$

In these equations, γ_{00} is the school grand mean, μ_{0j} is the random component of the mean score for class j, γ_{10}, γ_{20}, γ_{30}, γ_{40}, γ_{50}, and γ_{60} are the student slopes for gender, math anxiety, the interaction between gender and math anxiety, grade, the interaction between grade and math anxiety, and the interaction between grade, gender, and math anxiety for predicting math achievement. μ_{1j} and μ_{2j} are the school residuals related to gender and math anxiety slope.

The combined equation was:

$$
\begin{aligned}
math_{ij} = y_{00} + y_{10}(gender)_{ij} + y_{20}(MA)_{ij} + y_{30}(gender \times MA)_{ij} + y_{40}(grade)_{ij} \\
+ y_{50}(grade \times MA)_{ij} + y_{60}(grade \times gender \times MA)_{ij} + \mu_{0j} \\
+ \mu_{1j}(gender)_{ij} + \mu_{2j}\,(MA)_{ij} + e_{ij}
\end{aligned}
$$

Results

Tables 3 and 4 shows mean values and gender differences in tests for math anxiety and math achievement. Results showed math anxiety mean scores were higher for boys than for girls in grades 4 (boys vs. girls: 34.66 vs. 32.77) and Grade 8 (boys vs. girls: 28.71 vs. 26.64). Gender differences in math anxiety were significant ($F_{(1,24)} = 209.12$, $p < .001$). The interaction between gender and grade ($F_{(1,24)} = 0.45$, $p = .504$), gender and test version ($F_{(5,24)} = 0.72$, $p = .582$), and these three factors gender, grade, and test version ($F_{(5,24)} = 0.49$, $p = .785$) were not significant, indicating

Table 4 Multi-factor ANOVAs for math anxiety and math achievement

	Math anxiety				Math achievement			
	F	df	p	η^2_p	F	df	p	η^2_p
Gender	209.12	1	< 0.001	0.007	0.24	1	0.624	< 0.001
Grade	1931.02	1	< 0.001	0.064	23010.77	1	< 0.001	0.451
Test version	1.59	5	0.157	< 0.001	207.28	5	< 0.001	0.036
Gender × Grade	0.45	1	0.504	< 0.001	1.32	1	0.250	< 0.001
Gender × Test version	0.72	5	0.582	< 0.001	1.21	5	0.301	< 0.001
Grade × Test version	0.49	5	0.782	< 0.001	387.22	5	< 0.001	0.065
Gender × Grade × Test version	0.49	5	0.785	< 0.001	1.07	5	0.374	< 0.001

Table 5 Correlations between math anxiety and math achievement

	Grade 4			Grade 8		
	Boys	Girls	Total	Boys	Girls	Total
Test 1	− 0.066**	− 0.138***	− 0.097***	− 0.247***	− 0.253***	− 0.252***
Test 2	− 0.092***	− 0.133***	− 0.113***	− 0.181***	− 0.270***	− 0.225***
Test 3	− 0.085**	− 0.174***	− 0.129***	− 0.187***	− 0.287***	− 0.231***
Test 4	− 0.126***	− 0.145***	− 0.133***	− 0.208***	− 0.302***	− 0.254***
Test 5	− 0.100***	− 0.157***	− 0.125***	− 0.260***	− 0.348***	− 0.300***
Test 6	− 0.154***	− 0.119***	− 0.135***	− 0.186***	− 0.282***	− 0.229***
Total	− 0.105***	− 0.144***	− 0.122***	− 0.212***	− 0.290***	− 0.248***

*Notes: **p < .01, ***p < .001*

Table 6 Fixed effects and random effects from the random coefficient model

Fixed-effect	Coefficient	SE	t
Intercept	− 0.25	0.026	-0.97
Gender	0.01	0.012	0.59
MA	− 0.26	0.014	-18.55***
Gender × MA	0.09	0.018	4.90***
Grade	− 0.03	0.030	-0.89
Grade × MA	0.15	0.018	8.83***
Grade × Gender × MA	− 0.06	0.023	-2.28**
Random effect	Estimate	SE	Wald Z
Intercept	0.16	0.010	15.85***
Gender	0.01	0.003	2.93**
MA	0.01	0.001	3.41**

*Notes: MA, math anxiety; **p < .01, ***p < .001.*

that gender differences in math anxiety were not affected by grade or test version. Although the gender difference in math anxiety was significant, the effect size was very small ($\eta^2_p = 0.007$). There was no gender difference in math achievement in Grade 4 (boys vs. girls: 34.51 vs. 34.53), and Grade 8 (boys vs. girls: 17.41 vs. 17.63), the gender main effect ($F_{(1,24)} = 0.24$, $p = .624$) and interaction between gender and grade ($F_{(1,24)} = 1.32$, $p = .25$), gender and test version ($F_{(5,24)} = 1.21$, $p = .301$), and these three factors ($F_{(5,24)} = 1.07$, $p = .374$) were not significant.

Table 5 shows the correlations between math anxiety and math achievement. Math anxiety was significantly negatively correlated with math achievement, as expected in Grade 4 ($r = -.122$, $p < .01$) and Grade 8 ($r = -.248$, $p < .01$). Table 6 shows the random coefficient regression results for both grades. The fixed-effect analysis showed that math anxiety significantly predicted math achievement ($b = -0.26$, $p < .001$), but gender and grade did not. The gender × math-anxiety interaction was significant ($b = 0.09$, $p < .001$), meaning that while high anxiety predicted low achievement for both genders, this effect was more significant for girls (a significantly lower predicted achievement than for boys). Regarding gender, girls exhibited stronger negative correlations between math anxiety and math achievement. The grade × math-anxiety interaction was significant ($b = 0.15$, $p < .001$), meaning that age influenced the association between math anxiety and math achievement; negative correlations between math anxiety and math achievement were stronger in Grade 8 than in Grade 4. The grade × gender × math-anxiety interaction was also significant ($-b = 0.06$, $p < .01$), meaning that grade influenced the interaction between gender and math anxiety. We conducted random coefficient modeling for both grades separately. The ICCs for math achievement were 0.16 for Grade 4 and 0.18 for Grade 8. Table 7 shows that the gender × math-anxiety interaction was significant for both grades (Grade 4: $b = 0.03$, $p < .01$; Grade 8: $b = 0.10$, $p < .001$). The moderating effect of gender on the association between math anxiety and math achievement for each grade is depicted in Fig. 1.

Table 7 Fixed effects and random effects for the random coefficient model, separated by grade

	Grade 4			Grade 8		
Fixed-effect	Coefficient	SE	t	Coefficient	SE	t
Intercept	− 0.06	0.021	-2.71**	− 0.33	0.026	-1.27
Gender	0.01	0.021	0.35	− 0.01	0.031	-0.45
MA	− 0.09	0.019	-4.95***	− 0.26	0.026	-9.99***
Gender × MA	0.03	0.012	2.71**	0.10	0.014	7.40***
Random effect	Estimate	SE	Wald Z	Estimate	SE	Wald Z
Intercept	0.11	0.015	7.68***	0.10	0.016	6.16***
Gender	0.09	0.042	2.05*	0.07	0.021	3.23**
MA	− 0.01	0.210	-0.28	− 0.01	0.033	-0.15

*Notes: MA, math anxiety; *p < .05, **p < .01, ***p < .001*

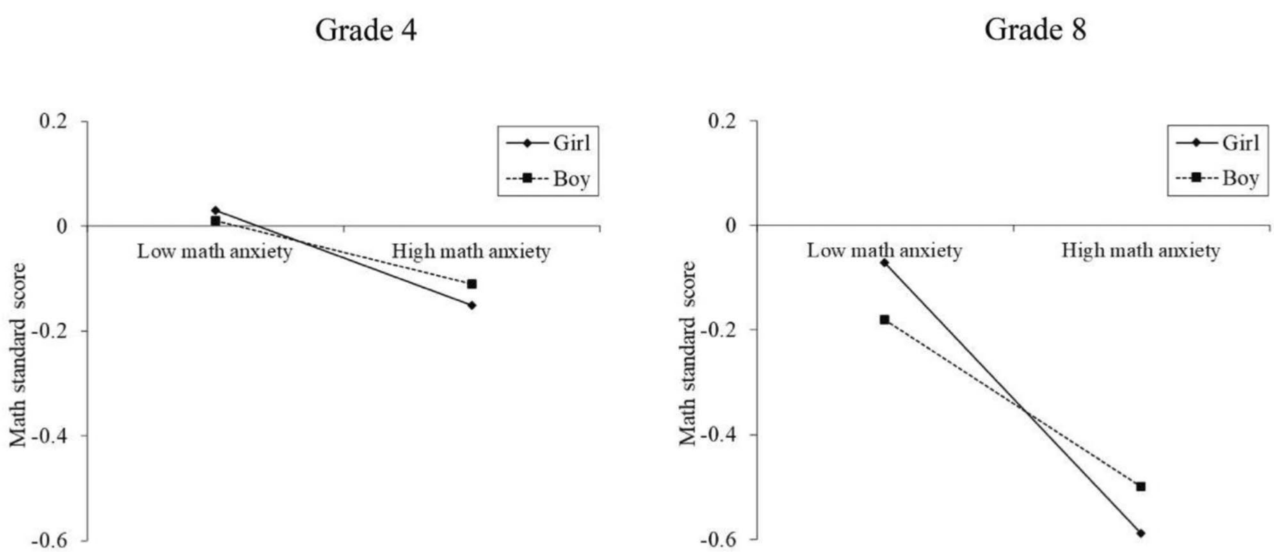

Fig. 1 Gender as a moderator between math anxiety and math achievement in fourth and eighth grades
Notes: In grade 4, the simple slope of math anxiety for girls was − 0.09, p < .001 and the simple slope of math anxiety on math achievement of boys was − 0.07, p < .001. In grade 8, the simple slope of math anxiety for girls was − 0.26, p < .001 and the simple slope of math anxiety on math achievement of boys was − 0.16, p < .001

Discussion

The current study examined gender differences in the relationship between math anxiety and math achievement in a large sample of elementary and secondary school students. Results showed significant negative correlations between math anxiety and math achievement for both boys and girls in Grades 4 and 8. Notably, the negative correlations were stronger for girls than for boys in both grades.

The relationship between math anxiety and math achievement

Results regarding the negative association between math anxiety and math achievement were consistent with previous studies (Ashcraft & Moore, 2009; Luttenberger et al., 2018; Wang, 2019). The Cognitive-Attentional theory can explain this negative link. This theory posits that high anxiety levels interfere with recall and occupy working memory capacity, thus resulting in poorer performance (Ashcraft, 2002; Ashcraft & Moore, 2009; Barroso et al., 2021; Carey et al., Devine, Hill, & Szűcs, 2017 ; Wine 1980).

Gender differences in math anxiety

We found significant gender differences in math anxiety, with boys reporting higher levels of math anxiety than girls. However, the effect size was small ($\eta^2_p = 0.007$). This result is inconsistent with other studies that found girls had higher levels of math anxiety than boys (Devine et al., 2012; Else-Quest et al., 2010; Hill et al., 2016; Ho et al., 2000; Xie et al., 2019; Yüksel-Şahin, 2008). There are several possible explanations for the discrepancies.

First, the results could reflect a cultural shift in China toward respecting female success in education and career. In recent years, the Chinese government has attached great importance to developing females' education and economy. The final monitoring report of the "outline for the development of Chinese women (2011–2020)" issued by the National Bureau of Statistics of China in 2021 showed that in 2020, the number of females receiving all kinds of higher education in China had exceeded that of males, accounting for 50.9% of all graduate students (Liu, 2022). The proportion of female employees in society was 43.5%, and the proportion of senior female professional and technical personnel increased. A study about gender differences in career perceptions in China has found that females and males have few differences in career goals and tactics (Granrose, 2007). Female and male employees were equally motivated to work hard, achieve, and do a good job. Furthermore, this gender cultural shift was also reflected in Qingdao, the sample city of this study. For example, a local survey of 1009 Qingdao citizens found no difference between the sexes regarding job promotion, and both males and females had equal opportunities, which showed that discrimination against females was reduced. The factors affecting job promotion currently were related to personal ability (Pang & Wang, 2011). On the other hand, recent research generally finds no gender difference in math performance among young adolescents (e.g., Hyde 2005; Liu, 2018; Mullis et al., 2016). Studies with Chinese students also showed that the gender gap in math performance was nonexistent (Tsui, 2007; OECD, 2015). For example, the PISA 2015 results showed that girls achieve the same level of math performance as boys in mainland Chinese cities (OECD, 2015). As mentioned in Keshavarzi and Ahmadi (2013), which found no significant differences in math anxiety between boys and girls, all societies are moving toward gender removal from mathematics. Females' success in mathematics and related fields breaks the stereotype that females are not good at mathematics, which makes girls in school more self-confident and interested in math. This may lead to reduced math anxiety and, in turn, reduced gender difference. From another perspective, with the success of females in mathematics, the stereotype that males are better than females may arouse suspicion among boys. Boys may not be more confident than girls in school, which may narrow their emotional differences in mathematics.

Second, teacher support is critical in students' school adjustment (Korlat et al., 2021; Ryan et al., 1994). Several studies reported lower levels of perceived teacher support among boys than among girls (Korlat et al., 2021; Reddy et al., 2003). Furthermore, boys were shown to express their negative academic emotions to their teachers less effectively than girls did (Lei et al., 2018). It has been shown that teacher support was negatively related to math anxiety (Aldrup et al., 2019; Li et al., 2021). Students who perceived low teacher support reported higher nervousness in mathematics (Rice et al., 2013). Therefore, boys' lower levels of perceived teacher support might explain this higher math anxiety than their female classmates.

Gender differences in math anxiety-achievement link

The results indicated a negative impact of math anxiety on math performance in both boys and girls, which was significantly higher for girls than for boys. This is inconsistent with the results reported in the previous meta-analysis that showed no gender differences (Barroso et al., 2021; Zhang et al., 2019).

These new results can be interpreted in several ways. First, they might be related to gender differences in emotional susceptibility and regulation. Those with math anxiety allocate more attention to negative emotions and worries, lowering the available working memory capacity and reducing the ability to solve math problems. Therefore, regulating negative emotions is particularly important for alleviating the negative impact of math anxiety on math performance. Studies have shown gender differences in emotional susceptibility and emotion regulation (Mak et al., 2009; Yuan et al., 2010). Females were more sensitive to negative emotions and were impacted by them more than males (Gard & Kring, 2007; Li et al., 2008; Yuan et al., 2010). Furthermore, functional magnetic resonance imaging showed that males had significant activation in cognitive regions, primarily the left parietal gyrus and the temporal-parieto-occipital region, under cognitive and emotional influences. In contrast, female participants showed significant activation in emotional regions such as the left amygdala and the right orbitofrontal cortex (Koch et al., 2007). This finding indicates that gender-specific processing is associated with the interplay of emotional and cognitive processes. Therefore, through this mechanism, math anxiety has a more significant negative impact on math performance in girls.

Second, the results might be related to the time limit that we employed. Tsui and Mazzocco (2006) tested sixth graders and showed that math performance differed between timed and untimed testing only for girls but not for boys, regardless of the level of math anxiety. Based on this, it might be that for girls in our test. The time pressure strengthened the negative impact of math anxiety on math performance.

Finally, perhaps the results were related to gender differences in self-perception of math anxiety. Females are more self-critical of math anxiety than males and view the consequences of math anxiety as more serious (Flessati & Jamieson, 1991). Compared with girls, boys are more likely to accept math anxiety and adopt reasonable ways to deal with it, thereby reducing its negative impact on math performance (Ashcraft & Ridley, 2005; Flessati & Jamieson, 1991). For girls, felt pressure is related to a reduced self-perception of math ability through an increase in learning math anxiety (John et al., 2022). Although a few studies have found that the correlation coefficient for girls is higher than for boys, they did not perform contrasts to prove the gender difference in the relationship statistically. Additionally, the sample sizes involved were small (Hill et al., 2016; Kyttälä & Björn, 2014; Olmez & Ozel, 2012). Based on a large sample, our research not only found that the correlation coefficient between math anxiety and math performance differs between boys and girls, but we also tested the difference and showed that the gender difference was statistically significant.

Grade differences in the math anxiety-achievement link

We found a negative correlation between math anxiety and math scores in the fourth and eighth grades. Further analysis indicated that the negative influence is developmental, with the older students showing higher correlations. This result was in line with recent studies (Devine et al., 2012; Dowker et al., 2012; Hill et al., 2016). We obtained grade differences based on large sample sizes and multiple test versions, indicating that the result is stable and consistent. The increase in correlation with age could be related to the increase in difficulty as math curriculum and exams progress to more complicated math. Studies have shown that math anxiety has the most significant negative impact when the problems are complex. For instance, compared with simple numerical operations, math anxiety significantly impacted mathematical problems requiring verbal reasoning and problem-solving (Wu et al., 2012). Ashcraft (2007) found that achievement was not lower than expected for highly math-anxious individuals when tested on the whole-number arithmetic taught in elementary school. Furthermore, as junior high school students have just entered adolescence, their moods are unstable, and significant physical and psychological changes have occurred (Brown & Larson, 2002; Yang et al., 2018; Yurgelun-Todd, 2007). For example, Yang et al. (2018) found lower positive mood ratings for mid-/late than pre-/early pubertal subjects. Furthermore, puberty selectively intensifies girls' attention bias for negative stimuli. These changes might undoubtedly influence how students engage in math and their emotional reactions (Cole & Hall, 2008; Sebastian et al., 2008).

Implications, limitations, and future studies

Math anxiety has a negative impact on math performance. We explored gender and grade differences in this relationship, and the results can help influence guides for teaching styles and provide an operable path for reducing the impact of math anxiety on math performance, thereby improving math performance. Our study found that the impact of math anxiety on math performance depends on gender and age; the impact was stronger in girls than in boys and stronger in eighth graders than in fourth graders. These results can guide teachers to pay more attention to girls who experience negative emotions related to math and to avoid using gender stereotypes related to math anxiety and math performance. Because the relationship between math anxiety and math achievement becomes stronger with age, we should take preventive measures when students are young and pay more attention to the emotional changes of middle school students. At the same time, as children advance in grade, math courses become more difficult. We should help students adjust their learning methods and relieve anxiety. Some research has shown that a solid foundation in mathematical knowledge is beneficial for relieving math anxiety and improving math performance (Beilock & Willingham, 2014).

This study was not without limitations. First, we did not consider the effect of time pressure on test anxiety. A study has shown a significant difference in math performance between timed and untimed testing in girls but not in boys, regardless of the level of math anxiety (Tsui & Mazzocco, 2006). Results from correlational and confirmatory factor analytic techniques showed that math anxiety correlated highly with test anxiety (Kazelskis et al., 2000). Frenzel et al. (2007) indicated that math test anxiety generally involves thinking about problems; when math problems involve mathematical thinking, girls tend to be more anxious than boys. However, we provided enough time for the math test, and the results did show any significant gender differences in math achievement. Nevertheless, future studies should control for time pressure and test anxiety. Second, considering the time limit of large-scale education quality monitoring, this study did not involve enough control variables, such as the general anxiety level of students, which was used as a control variable in previous studies (e.g., Cargnelutti et al., 2017; Hill et al., 2016). Although math anxiety was proved to be a stable and independent psychological construct separate from other social-emotional attitudes (Cheng et al., 2022), future studies should include more reasonable control variables. Third, we did not subdivide the math tests based on the type of math (e.g., calculation, geometry, and logical reasoning). Boys and girls might be good at different types of math, and anxiety might be eased when they complete such tasks (Miller, 2004). Therefore, math performance tests in future studies should be divided into modules that cover different types of math. Last, the samples of this study were only from Qingdao, and the representativeness has certain limitations. Future studies could be extended to more diverse samples to investigate gender differences in the link between math anxiety and math achievement.

Conclusion

The results of this study indicate that math anxiety harms math performance and that this relationship depends on gender and grade level. Specifically, the math anxiety-achievement link was stronger among girls than boys and students in Grade 8 than in Grade 4. These results can help us further to understand the relationship between math anxiety and math performance and can guide the emphasis on math instruction. When teaching, we should pay more attention to how girls react emotionally to math and the fluctuating achievements of older students.

Acknowledgements This study has been supported by the STI 2030—Major Projects 2021ZD0200500, the MOE (Ministry of Education of the People's Republic of China) Project of Humanities and Social Sciences [No. 18YJC190030] and Qingdao Municipal Planning Project of Social Sciences [No. QDSKL2001017].

Author Contribution Xiaodan Yu, Haitao Wang and Xinlin Zhou designed experiment and revised the manuscript. Xiaodan Yu and Haitao Wang collected data. Xiaodan Yu, Huimin Zhou, Panpan Sheng, Bingqian Ren analysed data and wrote the manuscript. Yiguo Wang revised the manuscript.

Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflicts of interest/Competing interests On behalf of all authors, the corresponding author states that there is no conflict of interest.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Informed consent was obtained from legal guardian in the case of children under 16.

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