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The factor structure of mathematics anxiety and its relation to gender and mathematics performance

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Abstract

Mathematics anxiety (MA) refers to negative cognition and negative affect that interfere with mathematics performance. We examined the dimensionality of MA, measurement invariance across males and females, and whether the strength of relations between MA and mathematics performance varies by dimension and gender among 245 sixth-grade students. Students were assessed on MA, arithmetic fluency, and on-grade-level computation skills. The confirmatory factor analysis and measurement invariance tests indicated that two distinct dimensions, cognition and affect, best represent MA across both genders. For the full sample, on-grade-level computation skills showed a significant negative relation with the cognitive dimension only, whereas arithmetic fluency was not significantly related to either dimension. We did not find any significant gender differences. Our findings provide support for the cognitive and affective model of MA and negative impact of MA on mathematics performance. Our findings further suggest incorporating the cognitive component in identifying and alleviating MA, and improving mathematics outcomes.

KEYWORDS

affect, cognition, dimensions of mathematics anxiety, mathematics anxiety

1 | INTRODUCTION

Mathematics anxiety (MA) refers to the negative emotions (e.g., feelings of tension and fear), physiological reactions (e.g., heart palpitation and sweaty palms), and worries that interfere with solving mathematics problems in daily life and academic situations (Richardson & Suinn, 1972; Wigfield & Meece, 1988). MA has been found to be consistently related to poor mathematics performance with the negative correlation between MA and mathematics performance ranging from −0.27 to −0.34 (see Hembree, 1990; Ma, 1999; Namkung et al., 2019 for meta-analyses). Several hypotheses regarding the direction of the relation between MA and mathematics performance have been suggested. A deficit model posits that prior negative experiences and mathematics skills deficit lead to subsequent MA (Hembree, 1990). On the other hand, an interference model suggests that MA affects subsequent mathematics performance during preprocessing (e.g., avoidance taking mathematics courses), and processing and recall (e.g., worries and intrusive thoughts taking up cognitive resources that would otherwise be available for mathematics tasks). However, a more recent meta-analysis (Namkung et al., 2019) suggested a bidirectional model, in which MA and mathematics performance mutually affect each other with a robust relation between MA and mathematics performance both concurrently and longitudinally. Regardless of the direction of effects, awareness of MA has been increasing with more recent studies indicating that children as young as kindergarteners experience significant MA (e.g., Aarnos & Perkkilä, 2012; Ganley & McGraw, 2016; Krinzinger et al., 2009; Ramirez et al., 2013).

MA is a multidimensional construct that is related to but distinct from other forms of anxiety, such as social anxiety and general anxiety (Ashcraft & Moore, 2009; Vukovic et al., 2013). Self-reported questionnaires have been used exclusively to measure MA (e.g., Mathematics Anxiety Rating Scale [MARS] in Richardson & Suinn, 1972; Math Anxiety Questionnaire [MAQ] in Wigfield & Meece, 1988). These measures have been assessed to examine the dimensionality of MA. Most of the MA literature examining the factor structures of MA has focused on mathematics performance and learning anxiety versus mathematics testing anxiety (e.g., Caviola et al., 2017; Cipora et al., 2015; Hopko et al., 2003; Jameson, 2013; Martín-Puga et al., 2020; Primi et al., 2020; Vahedi & Farrokhi, 2011). For example, researchers have found that MARS consists of two distinct dimensions, items related to negative emotions performing mathematics in nonevaluative situations and negative emotions in evaluative situations, such as testing situations (Rounds & Hendel, 1980; Suinn & Edwards, 1982).

However, another important way to conceptualize the dimensions of MA is based on the theoretical and empirical models of test anxiety (e.g., Liebert & Morris, 1967; Mandler & Sarason, 1952). Test anxiety is conceptualized as two components, *negative cognition*, which consists of self-deprecatory thoughts and worries about one's performance and *negative affect*, which is the emotional component that includes nervousness, tensions, and unpleasant physiological reactions (e.g., heart palpitation, stomachache) to testing situations (Liebert & Morris, 1967). These two components are correlated, but distinct. In the test anxiety literature, the cognitive component has been found to be more strongly related to poor test performance, interfering more with student achievement than the affective component (Sharma & Rao, 1983; Spiegler et al., 1968; Williams, 1991). According to this line of literature, the cognitive component of test anxiety produces self-deprecating and irrelevant thoughts, which in turn distract individuals from focusing on solving problems at hand (Ho et al., 2000).

Because MA may be a subject-specific manifestation of test anxiety (e.g., Bandalos et al., 1995; Dew et al., 1984), MA can also be conceptualized as negative affect and negative cognition that interfere with solving mathematics problems at hand (Ho et al., 2000; Meece et al., 1990; Richardson & Suinn, 1972; Wigfield & Meece, 1988). Addressing both cognitive and affective dimensions of MA may be particularly important because the MA dimensions may moderate the relation between MA and mathematics performance. Moreover, Namkung et al. (2019) found that MA measures that included both cognitive and affective dimensions showed the strongest relation to mathematics performance, suggesting the importance of addressing both components in identifying and alleviating MA. However, most studies in the MA literature either do not differentiate between the affective and cognitive dimension (e.g., Ashcraft & Kirk, 2001; Ramirez et al., 2013; Vukovic et al., 2013) or assess only the affective dimension (e.g., Carey et al., 2016; Caviola et al., 2017; Hill et al., 2016; Wang et al., 2018). Only a few studies have examined the cognitive and affective dimensions of MA with mixed findings on the strength of the relation between the dimension of MA and mathematics performance, and gender differences.

2 | COGNITIVE AND AFFECTIVE DIMENSIONS OF MA

Wigfield and Meece (1988) were the first to explore the cognitive and affective dimensions of MA among 564 sixth through 12th graders. The 11 item-MAQ was designed to measure cognitive (e.g., worry) and affective (e.g., fear, dread, nervousness) components of MA. An exploratory factor analysis indicated that the two-factor model best described the data. A follow-up measurement invariance model further supported the two-factor model across both genders and grade levels. Although the cognitive and affective dimensions were moderately correlated with each other ($r = .40$), there were significant differences in the strength of relation to mathematics performance. Whereas the affective dimension had a significantly negative correlation with mathematics performance at both Years 1 and 2 of the study ($r = -.22, -.26$, respectively), the cognitive dimension showed a negligible relation to mathematics performance at both years ($r = .02$ in both years). This finding contrasts with the test anxiety literature, in which the cognitive dimension has been found to be more disruptive to student performance than the affective dimension. No significant gender differences were found in the cognitive dimension. By contrast, girls reported having higher MA than boys in the affective dimension.

Similarly, Pajares and Urdan (1996) examined the factor structures of the 10-item MA Scale, adapted from the anxiety subscale of the Fennema–Sherman Mathematics Attitudes Scales (Fennema & Sherman, 1976) among middle school, high school, and college students. In line with Wigfield and Meece (1988), the exploratory factor analysis supported a two-factor model, a cognitive factor that reflected worry about mathematics tests, problems, and courses, and an affective factor that reflected negative feelings and emotions toward mathematics. These two factors correlated significantly for all sample ages ($.56 < rs < .68$). Although female high school and college students reported higher MA than did males, the factor structures were similar for females and males. No significant gender differences in MA were found at middle school. However, in contrast to the findings in Wigfield and Meece (1988), the cognitive factor accounted for most of the variance in the high school and college samples, whereas the affective factor accounted for more variance in the middle school sample. The authors suggested that this may be due to younger students having poorer emotion regulation skills.

The two-factor model distinguishing the affective and cognitive dimensions was also supported in a cross-cultural study comparing the factor structure of MA among sixth graders in China ($n = 211$), Taiwan ($n = 214$), and the United States ($n = 246$; Ho et al., 2000). Whereas the affective dimension had a significantly negative correlation with mathematics achievement in the Chinese ($r = -.68$), Taiwanese ($r = -.54$), and the United States ($r = -.57$) samples, the cognitive dimension showed an inconsistent relation to mathematics achievement. The cognitive dimension was not significantly related to the Chinese and US samples. As suggested by Pajares and Urdan (1996), younger students' mathematics performance may be more affected by negative affect for the Chinese and US samples. However, the cognitive dimension was significantly correlated with mathematics achievement for the Taiwanese sample ($r = .25$). Inconsistent findings were also reported regarding gender differences. Taiwanese girls reported having higher MA than boys in both affective and cognitive dimensions, whereas girls in the United States showed higher MA in only the cognitive dimension, which is in contrast of the finding in Wigfield and Meece (1988). There were no significant gender differences in the Chinese sample for either dimension.

The two-factor model of MA was extended to kindergarteners in Lu et al. (2021) although they focused on negative cognition and one subcomponent of negative affect, physiological reactions, on the Young Children's Math Anxiety Scale (YCMAX). The authors conducted both exploratory and confirmatory factor analyses with two comparable subsamples of 355 kindergarteners selected at random. The results from both analyses supported the two-factor model, worry and physiological reaction. In contrast to other studies, both dimensions of children's MA were negatively correlated with mathematics achievement (−.32 < *r*s < −.16, all *p*s < .01). However, the authors did not examine gender differences and whether the strengths of the correlations with mathematics achievement were significantly different between the two dimensions. More importantly, the negative cognition items on YCMAX tapped emotional components to a greater degree than in other studies, such as feelings of nervousness, which may partly explain different patterns of findings in Lu et al. (2021).

Taken together, although limited research exists, prior MA literature provides consistent evidence that the affective and cognitive dimensions of MA are distinct, supporting the two-factor model in line with the test anxiety theory. Despite the scarce, yet consistent evidence distinguishing the cognitive and affective dimensions, the current MA literature relies on an unidimensional model, and exclusively assesses the affective dimension only or reports only the overall MA as previously discussed. For example, in Namkung et al.'s review of MA measures (2019), only eight studies were found to assess the cognitive dimension, whereas 76 studies assessed the affective dimension. Thus, we aim to contribute to the growing literature on the dimensionality of MA and provide further guidance on how MA should be conceptualized, assessed, and treated. Additionally, clarity is needed regarding the strength of relation between the dimensions of MA and mathematics performance. As previously discussed, some studies support the affective dimension as a consistent contributor to poor mathematics performance (e.g., Ho et al., 2000; Wigfield & Meece, 1988), whereas some other studies and the test anxiety literature support the cognitive dimension as a key contributor to poor mathematics performance for middle schoolers and Taiwanese students (e.g., Ho et al., 2000; Pajares & Urdan, 1996). Yet, others have found no significant differences between the affective and cognitive dimensions regarding the strength of relation to mathematics performance (e.g., Namkung et al., 2019).

Another inconsistent finding reported in prior research that warrants further investigation is the presence or absence of gender differences in MA. Some studies have found that females, especially adults and secondary female students, reported significantly higher MA than males (e.g., Change & Cho, 2013; Devine et al., 2012; Ferguson et al., 2015; Hill et al., 2016; Primi et al., 2014), whereas others have found no significant gender differences in MA (e.g., Birgin et al., 2010; Dowker et al., 2012; Jansen et al., 2013; Ramirez et al., 2013). Researchers have suggested that higher MA among females may be reflective of social and cultural norms (Devine et al., 2012; Hembree, 1990; Hill et al., 2016). That is, it is more socially acceptable for females to admit and express negative emotions than males, and females may view themselves as less mathematically competent than males. This suggests that females may report higher MA, especially in the affective dimension, than do males (even if they do not actually experience more MA than do males). However, with respect to the cognitive and affective dimensions of MA across males and females, female students were found to have higher MA in the affective dimension only in Wigfield and Meece (1988). In contrast, female students in the United States showed higher MA in only the cognitive dimension in Ho et al. (2000). Yet, Taiwanese female students were found to report higher MA in both affective and cognitive dimensions than male students in Ho et al. (2000). Additional research is needed to clarify inconsistencies across studies in the degree to which females and males experience MA differently.

Additionally, whether the gender difference found in MA transfers to a gender difference in the relation between MA and mathematics performance is unclear, and only limited studies exist. Some studies have found a significantly negative correlation between MA and mathematics performance only in females (e.g., Erturan & Jansen, 2015; Devine et al., 2012; Hill et al., 2016; Schleepen & Van Mier, 2016). On the other hand, other studies have found a stronger negative correlation between MA and mathematics performance for males compared to females (e.g., Ma & Xu, 2004; Miller & Bichsel, 2004). Some argue that the stronger negative correlation between MA and mathematics performance among females may be because males are better able to inhibit their MA than females, thereby exerting less negative impact on males' mathematics performance (Hopko et al., 1998) whereas others argue that females are more prone to experiencing MA regardless of their true mathematics abilities, leading to a stronger negative correlation between MA and mathematics performance among males (Devine et al., 2012). Thus, gender differences in the relation between MA and mathematics performance warrant further attention. Therefore, the purposes of current study were to (1) examine the dimensionality of MA, (2) examine measurement invariance across males and females, and (3) examine whether the strength of relations between MA and mathematics performance varies by dimension and gender. We adapted the MAQ developed by Wigfield & Meece (1988), which measures both cognitive and affective dimensions of MA. Examining the dimensionality of MA will add to the growing evidence on the affective versus cognitive factor model of MA. Moreover, clarifying the strengths of the relation and gender differences across the affective and cognitive dimensions of MA will shed light on where intervention efforts should be focused as well as assessment targets. That is, if a stronger relation between the cognitive dimension and mathematics performance is found across males and females, it calls for revising the current MA assessment to include more items that assess the cognitive dimension. If gender differences are found in the relation between the dimensions of MA and mathematics performance, it will inform more differentiated approaches to alleviating MA for females versus males. To these ends, we asked the following research questions:

1. What is the factor structure of MA?
   a. Does the two-factor (affect and cognition) or one-factor model better characterize MA?
   b. Does the factor structure differ across males and females?
2. Do the relations between the dimensions of MA and mathematics performance (i.e., on-grade-level computation skills and arithmetic fluency) differ across males and females?

3 | METHOD

3.1 | Participants

The data described in this analysis were collected as part of another study examining the effects of equation-solving intervention for sixth-grade students with mathematics learning difficulties (Namkung & Bricko, 2021). Data for the present analysis were based on 243 sixth-grade students (n = 108 for females, n = 135 for males) from two middle schools in one urban and one suburban school district in a midwestern state. Aggregated demographic data for the two participating schools were obtained from the National Center for Education Statistics (National Center for Education Statistics, US Department of Education, 2022). The students at the urban middle school were 43.8% female, 54.5% White, 19.5% Hispanic, 8.8% Black, and 2.2% Asian, and 66.7% received free/reduced-priced lunch. The students at the suburban middle school were 47.5% female, 93.3% White, 2.9% Hispanic, 1.1% Black, and 0.2% Asian, and 20.1% received free/reduced-priced lunch. Table 1 shows the mean and standard deviation for the MA questionnaire and two mathematics measures by gender. There were no significant gender differences between MA and two mathematics measures (all $ps > .05$).

3.2 | Measures

3.2.1 | MA

The MAQ developed by Wigfield & Meece (1988) was adapted in the present study. One item that asked about how much a student worries about how well he/she is doing in school was replaced by an item related to a physiological reaction (i.e., I have butterflies in my stomach before I go to math class) because the item was not specific to mathematics but targeted general worries about performance in school. Thus, six statements targeting affect (e.g., When I am in math class, I feel nervous) and five statements targeting cognition (e.g., When teacher asks me math questions, I worry that I will do poorly) were included on the revised MA questionnaire. Students respond to 11 situational statements using a scale ranging from 1 (never) to 5 (always). Items are scored based on selected

TABLE 1 Descriptive statistics and correlations of MA and mathematics outcome variables.

	Computation		Math fact fluency		MA Coge		MA Aff		MA Tot					
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*				
Full sample (N = 243)	16.83	7.64	17.93	7.24	12.18	4.75	12.56	5.10	24.75	9.13				
Males (n = 135)	17.28	7.90	18.16	7.07	11.80	4.70	12.33	5.06	24.13	9.08				
Females (n = 108)	16.28	7.37	17.64	7.51	12.64	4.80	12.89	5.16	25.54	9.19				

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. MA1															
2. MA2	.66														
3. MA3	.61	.65													
4. MA4	.41	.37	.36												
5. MA5	.44	.46	.35	.30											
6. MA6	.55	.54	.50	.46	.45										
7. MA7	.53	.53	.55	.50	.40	.58									
8. MA8	.48	.39	.40	.40	.37	.42	.45								
9. MA9	.32	.35	.25	.31	.21**	.48	.46	.29							
10. MA10	.54	.41	.35	.39	.40	.42	.46	.39	.39						
11. MA11	.42	.37	.35	.45	.38	.50	.48	.42	.45	.60					
12. MA Cog	.62	.54	.49	.70	.45	.65	.77	.52	.70	.76	.80				

TABLE 1 (Continued)

		Computation		Math fact fluency		MA Coge		MA Aff		MA Tot					
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*				
13. MA Aff	.82	.82	.78	.50	.70	.77	.63	.66	.42	.55	.55	.72			
14. MA Tot	.78	.74	.70	.65	.63	.77	.77	.62	.60	.71	.73	.92	.93		
15. MComp	−.23	−.23	−.25	−.30	−.27	−.27	−.31	−.16*	$-.10^{ns}$	−.26	−.30	−.34	−.32	−.35	
16. MBSP	−.18**	−.18**	−.25	−.28	−.28	−.22	−.24	$-.09^{ns}$	$-.06^{ns}$	−.16*	−.16*	−.24	−.28	−.28	.64

Note. All correlations statistically significant at $p < .001$ unless otherwise noted.

Abbreviations: MA, mathematics anxiety; MA Aff, mathematics anxiety affective dimension; MA Cog, mathematics anxiety cognitive dimension; MA Tot, mathematics anxiety total; MComp, on-grade level mathematics computation; MBSP, arithmetic fluency; ns, nonsignificant; SD, standard deviation.

*$p < .05$; **$p < .01$.

responses: never = 1 point, rarely = 2 points, sometimes = 3 points, often = 4 points, and always = 5 points. Total score is the sum of the number of points for each item. Higher scores indicate more anxious or negative reactions to mathematics.

3.2.2 | Mathematics performance

AIMSweb Mathematics Computation is a standardized, norm-referenced test of comprehensive mathematics computation skills. Items on a sixth-grade probe include multiplying and dividing whole numbers (8 items), adding and subtracting positive and negative integers (5 items), adding, subtracting, dividing, and multiplying fractions and decimals (15 items), converting between decimals and fractions (4 items), simplifying fractions (4 items), and evaluating algebraic expressions (4 items). Students have 8 min to complete as many problems as possible. Each item is scored as correct or incorrect with 40 total points possible. Alternate-form reliability at sixth grade is 0.89.

Monitoring Basic Skills Progress is a standardized curriculum-based measure developed by Fuchs et al. (1990) to monitor student progress in arithmetic fluency. We used a third-grade probe (a) to distinguish from on-grade level computation skills that target more advanced skills (e.g., solving algebraic equations) that students may or may not have learned yet and (b) to assess students' fluency with foundational computation skills that most sixth graders should be competent with. Items include addition with regrouping (three items), subtraction with regrouping (five items), multiplication of basic facts (nine items), multiplication with regrouping (two items), and division of basic facts (six items). Students have 3 min to complete as many problems as possible. Each item is scored as correct or incorrect with 25 total points possible. Test–retest reliability is 0.81.

3.3 | Data analysis plan

To address the primary research question, we first conducted confirmatory factor analysis to determine whether MA was best represented as a unidimensional construct or separate cognitive and affective dimensions using M*plus* (ver. 8.0; L. K. Muthén & Muthén, 1998–2017) with full information maximum likelihood estimation. Model fit was evaluated via global chi-square (χ^2) test and approximate fit indices, including (a) comparative fit index (CFI; values ≥ 0.90 for acceptable fit, values ≥ 0.95 for good fit), (b) Tucker–Lewis index (TLI; values ≥ 0.90 for acceptable fit, values ≥ 0.95 for good-fit), (c) root mean square error of approximation (RMSEA; values ≤ 0.08 for acceptable fit, values ≤ 0.05 for good fit), and (d) standardized root mean residual (SRMR; values ≤ 0.08 for acceptable fit, values ≤ 0.05 for good fit).

After determining the measurement structure, we evaluated measurement invariance across males and females. To evaluate measurement invariance, we sequentially conducted measurement invariance tests of nested models, in which (1) all parameters were freely estimated across groups, (2) all factor loadings were constrained to equality across groups (metric invariance), (3) all intercepts were constrained to equality across groups (scalar invariance), and (4) residual variances were constrained to equality across groups (strict invariance). Each model included all constraints in the prior the model (e.g., for the first model, only factor loadings were constrained to equality across groups; for the second model, factor loadings and intercepts were constrained to equality across groups). Significant decrements in model fit would indicate lack of measurement invariance, whereas no significant difference in model fit would indicate invariance across males and females, allowing comparisons of structural relations with mathematics outcomes across groups.

Following the establishment of measurement invariance, we evaluated whether MA was significantly related to mathematics outcomes. Specifically, we evaluated the relations between cognitive-specific MA and affect-specific MA with on-grade-level mathematics computation as well as arithmetic fluency outcomes. Wald χ^2 tests were used to determine whether a given parameter was significantly different across groups (e.g., whether the relation between cognitive-specific MA and on-grade-level mathematics computation differed for males and females).

4 | RESULTS

4.1 | Descriptive statistics

Descriptive statistics and correlations are reported in Table 1. Results of *t*-tests indicated there were no significant differences across males and females in on-grade-level computation skills, arithmetic fluency, MA cognitive dimension, MA affective dimension, or MA total (all $ps > .17$). Items on the MA questionnaire were consistently moderately to strongly correlated with one another ($0.21 <$ all $rs < .66$; all $ps < .01$). Additionally, MA items as well as the total score for MA were consistently correlated with both mathematics outcomes overall, although the strength of the relations were smaller than were the strength of the relations between MA items. As expected, on-grade-level computation skills and arithmetic fluency were strongly correlated with each other ($r = .64$, $p < .001$).

4.2 | Confirmatory factor analysis

Model fit indices for confirmatory factor analysis are reported in Table 2. Results indicated that a unidimensional (i.e., one factor) model did not provide adequate fit to the data. A two-factor model comprised of separate cognitive and affective MA factors fit the data significantly better than did the one factor model and provided adequate fit to the data. Standardized factor loadings for the two-factor model are presented in the upper panel of Table 3. All MA items loaded significantly onto the designated affect or cognition factor. Although the two-factor model fit the data better than did the unidimensional model, the correlation between the cognitive and affective factors was very large ($r = .87$, $p < .001$), indicating substantial shared variance between the different dimensions of MA.

TABLE 2 Model fit statistics for confirmatory factor analysis.

	χ^2	*df*	$\Delta\chi^2$	RMSEA	CFI	TLI	SRMR
Full sample							
1-Factor	151.41***	44		0.10	0.91	0.88	0.05
2-Factor	122.15***	43	29.26***	0.09	0.93	0.91	0.05
Female							
1-Factor	85.67***	44		0.09	0.92	0.90	0.06
2-Factor	64.61*	43	21.06***	0.07	0.96	0.95	0.05
Male							
1-Factor	120.83***	44		0.11	0.88	0.85	0.06
2-Factor	112.57***	43	8.26**	0.10	0.89	0.86	0.06

Note. Analysis run treating indicators as continuous variables.

Abbreviations: $\Delta\chi^2$, Chi-square difference test; CFI, comparative fit index; *df*, degrees of freedom; RMSEA, root mean square error of approximation; SRMR, standardized root mean residual; TLI, Tucker–Lewis index.

**p* < .05; ***p* < .01; ****p* < .001.

TABLE 3 Standardized factor loadings.

	1-Factor	2-Factor Affect	2-Factor Cognition
MAQ1	0.79***	0.81***	
MAQ2	0.74***	0.78***	
MAQ3	0.69***	0.72***	
MAQ4	0.59***		0.61***
MAQ5	0.57***	0.57***	
MAQ6	0.74***	0.72***	
MAQ7	0.74***		0.76***
MAQ8	0.60***	0.59***	
MAQ9	0.52***		0.56***
MAQ10	0.65***		0.69***
MAQ11	0.66***		0.72***

	Male		Female	
	Affect	Cognition	Affect	Cognition
MAQ1	0.79**		0.83***	
MAQ2	0.74***		0.80***	
MAQ3	0.66***		0.78***	
MAQ4		0.64***		0.57***
MAQ5	0.57***		0.57***	
MAQ6	0.79***		0.66***	
MAQ7		0.71***		0.83***
MAQ8	0.58***		0.62***	
MAQ9		0.58***		0.56***
MAQ10		0.67***		0.69***
MAQ11		0.69***		0.75***

**$p < .01$; ***$p < .001$.

4.3 | Measurement invariance

Results for tests of measurement invariance are reported in Table 4. To evaluate metric invariance across males and females, all factor loadings were constrained to equality across groups. The χ^2 difference test indicated that this model fit the data as well as the model in which all factor loadings were freely estimated across groups, $\Delta\chi^2(11) = 6.9$, $p = .81$, indicating achievement of metric invariance. To evaluate scalar invariance, all factor loadings and intercepts were restricted to equality across groups. This model fit the data as well as the model in which all factor loadings and intercepts were freely estimated across groups, $\Delta\chi^2(22) = 21.85$, $p = .47$, indicating achievement of scalar invariance. To evaluate strict invariance, we constrained the covariance of the two MA factors to equality across groups. This model fit the data as well as the model with all parameters freely estimated across groups,

TABLE 4 Model fit statistics for tests of measurement invariance.

	χ^2	*df*	$\Delta\chi^2$	RMSEA	CFI	TLI	SRMR
No constraints	177.17***	86		0.09	0.92	0.90	0.06
Factor loadings only	184.07***	97	6.90^{ns}	0.09	0.93	0.92	0.06
Factor loadings + intercepts	199.02***	108	21.85^{ns}	0.08	0.92	0.92	0.07
Factor loadings + intercepts + covariance	200.21***	109	23.04^{ns}	0.08	0.92	0.92	0.07
Factor loadings + intercepts + covariance + residuals	214.09***	120	36.92^{ns}	0.08	0.92	0.93	0.08

Abbreviations: $\Delta\chi^2$, Chi-square difference test; CFI, comparative fit index; *df*, degrees of freedom; ns, nonsignificant; RMSEA, root mean square error of approximation; SRMR, standardized root mean residual; TLI, Tucker–Lewis index.
***$p < .001$.

$\Delta\chi^2(23) = 23.04$, $p = .46$. An additional step of evaluating strict measurement invariance was evaluated, in which residual errors were constrained to equality across groups. This model fit the data as well as the model, in which all parameters were freely estimated across groups, $\Delta\chi^2(34) = 36.92$, $p = .34$, indicating achievement of strict measurement invariance. Achievement of strict measurement invariance across males and females allowed us to proceed with evaluations of structural models comparing relations between MA and mathematics outcomes across groups.

4.4 | Strength of relations by dimension and gender

To determine whether overall level of MA differed across males and females, we examined two separate models. In one model, the mean for affect-specific MA was freely estimated across groups and in the other, the mean for cognition-specific MA was freely estimated across groups. Each of these models was compared to the model, in which both factor means were constrained to equality across groups. χ^2 difference testing was conducted to determine whether freely estimating factor means resulted in improvements in model fit. For both affect- ($\Delta\chi^2[1] = 0.11$, $p = .74$) and cognition-specific MA ($\Delta\chi^2[1] = 1.69$, $p = .19$), χ^2 difference tests indicated no difference in factor means across males and females.

Before examining differences in structural relations across males and females, we evaluated the structural relations between MA and mathematics outcomes for the full sample. Model fit for the model including the structural relations between MA and mathematics outcomes was acceptable ($\chi^2[61] = 151.89$, $p < .001$, CFI = 0.93, TLI = 0.91, RMSEA = 0.08, SRMR = 0.05). Results indicated that the cognitive dimension was negatively related to students' on-grade-level computation skills ($\beta = -.46$, $p < .05$). In contrast, the relation between the affective dimension and on-grade-level computation skills was not statistically significant ($\beta = .08$, $p = .674$). Moreover, the relations between the cognitive ($\beta = -.14$, $p = .482$) and affective ($\beta = -.16$, $p = .436$) dimensions of MA with arithmetic fluency were not statistically significant. Together, cognition- and affect-specific MA factors accounted for 15.5% of the variance in on-grade mathematics computation outcomes and 8.0% of the variance in arithmetic fluency outcomes. This model is displayed in Figure 1.

When structural relations were modeled separately for males and females, model fit was acceptable ($\chi^2[106] = 196.69$, $p < .001$, CFI = 0.92, TLI = 0.92, RMSEA = 0.08, SRMR = 0.07). Relations of cognition- and affect-specific MA with mathematics outcomes were not statistically significant for females (for on-grade mathematics computation, cognition-specific MA $\beta = -.15$, $p = .536$, affect-specific MA $\beta = -.27$, $p = .272$; for foundational computation, cognition-specific MA $\beta = -.16$, $p = .512$, affect-specific MA $\beta = -.20$, $p = .414$). For males, the relation between cognition-specific MA and mathematics computation for males was marginally significant ($\beta = -.71$, $p = .058$), but the relation between affect-specific MA and on-grade level mathematics computation was not

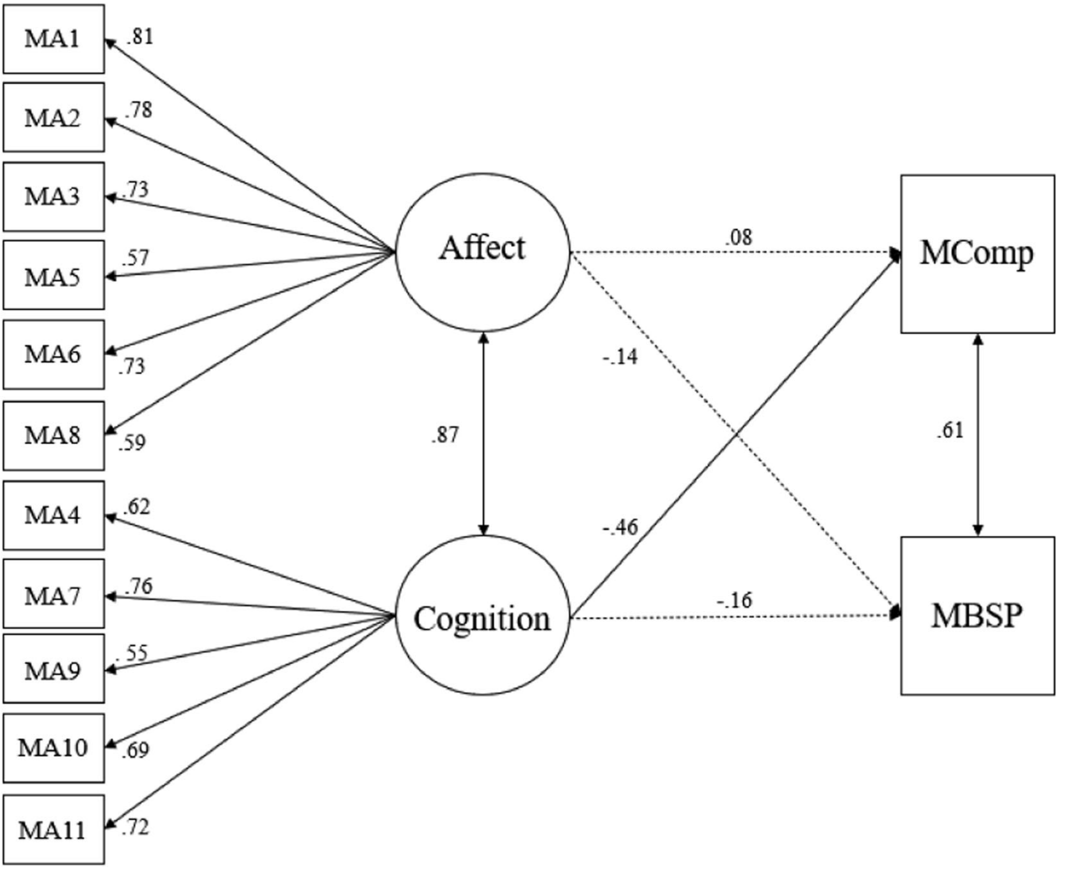

FIGURE 1 Structural relations between mathematics anxiety and mathematics outcomes for the full sample. Solid arrows indicate statistically significant paths.

statistically significant ($\beta = -.36$, $p = .334$). Relations between cognition-specific ($\beta = -.10$, $p = .786$) and affect-specific MA ($\beta = -.13$, $p = .714$) and foundational computation were not statistically significant. Wald tests evaluating whether structural relations were different across males and females were never significant, indicating no differences in the relations between MA and mathematics outcomes across groups.

5 | DISCUSSION

In line with previous studies and test anxiety theory, we found that two distinct dimensions, cognition and affect, best represent MA (e.g., Ho et al., 2000; Wigfield & Meece, 1988). Thus, our finding adds to the growing literature on the cognitive and affective model of MA. This has important implications for assessing MA. Namkung et al. (2019) found that MA is most often defined as affective in current literature, as evidenced by the relative lack of MA research using assessments that purportedly measure the cognitive dimension ($N = 8$ studies) compared to the affective dimension ($N = 76$ studies). MA measures should address both affective and cognitive dimensions to accurately index MA. At the same time, MA measures that incorporate both cognitive and affective components need to be developed and validated more carefully, as the distinction between cognitive and affective items on MA measures is not always clear for existing scales. For example, items that empirically load onto the cognitive dimension of MA may include emotion-related language (e.g., feelings of nervousness), depending on which MA measure was used (e.g., YCMAX in Lu et al., 2021). This yields potential uncertainty regarding the degree to which such an item measures cognition-specific MA independently of affect-specific MA. Also, some MA measures include items that tap other domains, such as attitudes toward mathematics (e.g., Bai, 2011), or use ambiguous questions (e.g., do mathematical symbols worry you?). Therefore, further research on valid cognition- and affect-specific MA items is needed.

Prior research has revealed gender differences in the degree to which individuals experience MA (Ho et al., 2000; Wigfield & Meece, 1988). However, we did not find overall differences in the levels of MA reported across males and females or for cognitive- or affect-specific MA. Both males and females also performed comparably on mathematic measures. We further evaluated whether the MA items used in this study measured underlying MA constructs equivalently across males and females. Results of measurement invariance testing did not reveal any gender differences in the underlying structure of MA, indicating that affective and cognitive dimensions of MA can be separated in both males and females. Thus, scores derived from this MA measure for both males and females can be compared, as they represent the same underlying constructs across groups. Although we did not observe differences in MA across males and females in this study, future research should explore the possibility of differences in different age groups, as our finding is inconsistent with some prior research demonstrating significant differences across males and females.

For our full sample of sixth graders, we did not find significant links between either the cognitive or affective dimension of MA and arithmetic fluency. However, for on-grade-level computation skills, we found a significant negative relation with the cognitive dimension, whereas the relation with the affective dimension was not significant. First, our arithmetic fluency measure targeted third-grade-level computation skills that most sixth graders should be competent with (e.g., addition and subtraction with regrouping, division facts). Therefore, our arithmetic fluency measure may have been too easy to arouse MA. This is consistent with the finding of Namkung et al. (2019) that advanced mathematics tasks that require multistep processes showed a stronger negative relation ($r = -.35$) to MA compared to foundational mathematics tasks ($r = -.20$). The stronger negative relation between advanced mathematics outcomes and MA was robust even when controlling for effects of other important variables, such as grade level, dimensions of MA, and impact on school grades.

Ashcraft and Faust (1994) reported a similar finding, in which college students' performance on basic arithmetic computation was not affected by MA whereas their performance on more advanced procedural computation was affected by MA. The authors explained that solving more complex mathematics problems increases cognitive demand on working memory, and anxiety about solving complex problems leads to an overload in working memory capacity, resulting in poorer mathematics performance. Thus, on-grade-level computation problems may have taxed working memory in our sample, and MA takes up valuable resources needed to tackle grade-level computation problems, which in turn leads to poorer mathematics performance. In contrast, most students should be able to recall answers to or solve arithmetic fluency items without much effort, so any working memory resources diverted to MA do not impact performance on these items. Future studies should explore the relation between working memory, dimensions of MA, and different mathematics outcomes to examine underlying mechanisms.

In this study, only the cognitive dimension of MA was significantly related to on-grade-level computation skills. In contrast, prior research has indicated that the affective dimension of MA shows a stronger relation to mathematics performance than does the cognitive dimension (Ho et al., 2000; Wigfield & Meece, 1988). However, Wigfield and Meece noted that ninth graders, in particular, reported higher MA in the cognitive dimension. Wigfield and Meece explained that although the affective dimension of MA, overall, has a stronger relation with mathematics performance, the ages of the samples and their environment may lead to discrepant results. The authors suggested that ninth graders who recently entered high school and shifted to a new environment, in which evaluation is emphasized, and students are tracked into different mathematics classes based on their performance may have experienced MA differently. That is, the significant changes that ninth graders experienced may have led them to have more concerns about their own mathematics ability, and intrusive thoughts about one's own ability may impair performance to a greater degree than negative emotions.

Likewise, our sample of sixth graders had just entered middle school and were tracked into different mathematics classes. This may have led to significant changes in the nature of how MA is experienced, resulting in a stronger relation between the cognitive dimension and mathematics performance. Although this finding may be sample-specific, and more studies with various age groups are needed to clarify, our finding also suggests that intervention efforts to improve mathematics outcome should incorporate alleviating MA, especially in the cognitive dimension. In fact, MA alone accounted for 15.5% of the variance in on-grade-level computation skills. This suggests that alleviating MA may be one key factor for improving mathematics outcomes.

When structural relations were modeled separately for males and females, we did not find any significant differences across males and females. Our findings provide additional support that the structure of MA and the negative impact of MA on mathematics performance for both dimensions of MA are similar across males and females. One possibility for the lack of gender differences we found may be related to the diminishing/disappearing gaps in mathematics performance across males and females (e.g., Devine et al., 2012; Hill et al., 2016; Lindberg et al., 2010). Female students may be overcoming the traditional gender stereotypes in Western cultures and experiencing similar levels of MA as male students (e.g., building more confidence and efficacy in mathematics). At the same time, it is also possible that male students are being taught more effective strategies to express and deal with their emotions and worries. However, it is important to note that our insignificant finding may have been due to reduced statistical power resulting from splitting the sample into males and females. For example, the relation between the cognitive dimension and on-grade-level computation skills was marginally significant for males but not females, with substantial differences in the magnitude of the standardized regression coefficient, but the test of whether the parameters were different from each other was not significant. Future studies should continue to explore gender-related differences in MA and in the relation between MA and mathematics performance with larger samples.

6 | LIMITATIONS

Our findings should be interpreted with the limitations in mind. First, we note that our sample size was relatively small. The small sample size may have limited our power to detect differences, especially when separate models were tested for females and males as discussed previously. However, posthoc examination of statistical power suggests that our study was adequately powered. According to Wolf et al. (2013), for a two-factor CFA with six indicators per factor and average standardized factor loadings of 0.65, a sample size of 120 is needed to obtain power of 0.80. Increasing the average factor loading to 0.80 decreased the sample size requirement to 100 to obtain power of 0.80. This corresponds closely with our analysis, which represented a two-factor CFA with six indicators for the affect-specific MA factor and five indicators for the cognition-specific MA factor. We had 108 females and 135 males in the sample, with average standardized factor loadings of 0.69 for females and 0.68 for males. Consequently, power was sufficient for males, and power was near 0.80 for females. Nevertheless, additional research with larger samples is needed to clarify gender differences in the nature of the relation between mathematics outcomes and dimensions of MA.

Second, we note that our model fit was not excellent, although acceptable. Consequently, the results of this study should be interpreted with caution. It is possible that a model that more accurately characterized the nature of variance in participant responses to MA questionnaires would yield different results regarding the nature of the relations between MA and mathematics outcomes in sixth-grade students. However, we do not believe that relatively poor model fit has serious implications for interpretation of results. After examining model modification indices, it became apparent that freeing four correlations among indicators substantially improved model fit. This better-fitting model retained strict measurement invariance and the overall pattern of results did not change.

Because the overall pattern and interpretation of results did not change after adjusting the model, we retained our original a priori hypothesized model.

Model misfit may have stemmed from the relatively small sample size as RMSEA can have artificially large values for models with small degrees of freedom (Kenny et al., 2014). Additionally, although our model was theoretically and empirically based on previous findings, there may have been other factors or aspects of MA that fit the data adequately that the current MAQ measure did not capture. Future studies should explore ways to improve the model fit as well as explore alternative ways of modeling the MA structure. One example to improve the model fit may be including general anxiety items that could be separated from MA.

Another limitation of our study relates to how MA was assessed. Students' MA was assessed with a self-reported questionnaire. Like with any self-reported questionnaires, student responses may have been clouded by their inaccurate perceptions. It is also possible the MA measure may have served as a proxy for mathematics performance. Future studies might explore using objective measures of MA (e.g., physiological measures such as heart rate or cortisol levels). Last, we note that students may not identify with a binary gender and that it is not clear how our findings may or may not generalize to students with a nonbinary gender.

7 | IMPLICATIONS FOR PRACTICE

Teachers, caregivers, and students should be aware that MA not only elicits negative emotions, but more importantly, worries and self-deprecatory thoughts, which have a negative impact on mathematics performance. Although more research is focused on alleviating the affective dimension of MA (e.g., recognizing emotions, relaxation, and systematic desensitization), MA intervention that had cognitive behavioral therapy components effectively reduced MA (e.g., Passolunghi et al., 2020; Zettle, 2003). Such strategies focused on turning negative thoughts and worries into positive thoughts, and identifying barriers and committing to actions to attain goals.

Additionally, teachers, caregivers, and students should take a preventive approach and be proactive about identifying, discussing, and alleviating MA, especially when significant changes in the student learning environment are expected. These changes may include introducing more difficult mathematical content, taking high-stakes mathematics assessments, and entering middle or high school.

8 | SUMMARY

In conclusion, our findings highlight that both cognitive and affective dimensions represent MA across males and females and that MA negatively impact students' mathematics performance. Specifically, foundational mathematics tasks may not arouse MA, whereas advanced mathematics tasks (e.g., on-grade-level mathematics tasks) may arouse MA and show a stronger negative relation with the cognitive dimension. However, the strength of the relation between mathematics performance and each dimension may change based on age and changes in the environment (e.g., entering middle school or high school, more emphasis on evaluation). The present study also provides support for addressing the cognitive dimension of MA (e.g., worries, self-deprecatory thoughts) in identifying and alleviating MA, and improving mathematics performance.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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