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Is Math Anxiety Always Bad for Math Learning? The Role of Math Motivation

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Abstract

The linear relations between math anxiety and math cognition have been frequently studied. However, the relations between anxiety and performance on complex cognitive tasks have been repeatedly demonstrated to follow a curvilinear fashion. In the current studies, we aimed to address the lack of attention given to the possibility of such complex interplay between emotion and cognition in the math-learning literature by exploring the relations among math anxiety, math motivation, and math cognition. In two samples—young adolescent twins and adult college students—results showed inverted-U relations between math anxiety and math performance in participants with high intrinsic math motivation and modest negative associations between math anxiety and math performance in participants with low intrinsic math motivation. However, this pattern was not observed in tasks assessing participants' nonsymbolic and symbolic number-estimation ability. These findings may help advance the understanding of mathematics-learning processes and provide important insights for treatment programs that target improving mathematics-learning experiences and mathematical skills.

Keywords

math anxiety, math motivation, math cognition, Yerkes-Dodson law

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Math anxiety is a feeling of tension, worry, and fear in situations involving math-related activities (Suinn & Winston, 2003). It has significant conceptual overlap with constructs related to general academic affect, such as test anxiety and academic self-confidence (Devine, Fawcett, Szucs, & Dowker, 2012), but also captures affective experiences unique to mathematic situations (Hembree, 1990). The relations between math anxiety and math cognition have been frequently studied, and the negative associations between the two have been observed at multiple levels of mathematical processing ranging from simple counting (Maloney, Risko, Ansari, & Fugelsang, 2010) to complex math-problem solving (Ramirez, Gunderson, Levine, & Beilock, 2013). These negative associations are evident across various developmental stages (Maloney et al., 2010; Ramirez et al., 2013).

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However, to conclude that math anxiety uniformly impairs the development of math cognition might not fully capture the potentially complex interplay between emotion and cognition. The animal-learning and cognitive-psychology literatures have demonstrated complex relations among stress, emotional arousal, and cognitive performance. These studies have revealed that, in rats, an intermediate level of stress produced optimal learning efficiency of complex tasks, whereas both extremely low and high levels of stress produced poor learning efficiency (Yerkes & Dodson, 1908). This inverted-U law has since been extended to the relation between negative emotions, such as anxiety, and performance in complex memory and attention tasks that rely heavily on prefrontal cortex functioning in primates (Andreano & Cahill, 2006; Aston-Jones, Rajkowski, & Cohen, 2000; Mendl, 1999). At the behavioral level, a moderate amount of anxiety is believed to heighten alertness and focus attention, which facilitates complex cognitive functioning, whereas high anxiety impairs performance by diverting resources away from cognitive performance. More recent studies have demonstrated that central neurochemical activities (e.g., catecholamine release and signaling) may underlie the observed curvilinear relationship between anxiety and complex cognitive performance (Arnsten, 2009; Diamond, Campbell, Park, Halonen, & Zoladz, 2007). Therefore, given that these complex cognitive functions are crucial to mathematical processing (Ashcraft, 2002), it is plausible that a quadratic curvilinear relation between math performance and specific anxiety about math should be observed. Two previous studies have provided some preliminary evidence suggesting that moderate levels of math anxiety facilitate math performance in adults and mathematically gifted children (Evans, 2000; Tsui & Mazzocco, 2006). Thus, our first aim in the current study was to examine whether math performance varies as a quadratic curvilinear function of math anxiety in a student population of normal achievers.

Another important affective aspect involved in math cognition is motivation (Middleton & Spanias, 1999; Vallerand et al., 1992). Math motivation captures the extent to which individuals embrace math challenges, value the importance of math abilities, and are motivated to perform well in math (Gottfried, Marcoulides, Gottfried, Oliver, & Guerin, 2007). Math anxiety and math motivation are two related but distinct dimensions of math affect. Math anxiety captures nervousness and discomfort in math experiences but offers little information on how individuals approach math-related activities to relieve these negative feelings. Math motivation defines approach- versus withdrawal-oriented response tendencies toward math. Math anxiety and math motivation are related in that they both capture some hedonic (i.e., negative vs. positive) aspects of math experience, and both have been shown to be modestly negatively correlated (L. Chiu & Henry, 1990). However, items measuring math anxiety and math motivation have been found to load on separate factors, which shows that they are distinct constructs (Bai, Wang, Pan, & Frey, 2009; Krinzinger, Kaufmann, & Willmes, 2009). Some highly math-anxious individuals are more avoidant in math, whereas others invest more effort and recruit more cognitive resources in math problem solving (Lyons & Beilock, 2012; Wigfield & Meece, 1988). Such a multidimensional conceptualization of math-related affect is also consistent with the emotion literature that points to the bidimensionality in affective evaluative space (Norris, Gollan, Berntson, & Cacioppo, 2010) and the distinction between motivational direction and affective valence (Harmon-Jones, Gable, & Peterson, 2010).

Math anxiety and math motivation together improve prediction of math-learning behaviors and achievement outcomes compared with either one alone (Lyons & Beilock, 2012; Wigfield & Meece, 1988). In particular, one recent study showed that high activations in brain regions involved in motivating behaviors dampen the negative effects of high math anxiety on math performance; this suggests that math performance varies not only as a function of math anxiety, but also as a function of how individuals approach math-related situations (Lyons & Beilock, 2012). However, given the exclusive focus on extremely high and low math anxiety in Lyons and Beilock's study, it is ultimately unclear how motivation interacts with math anxiety across the full range of math anxiety in predicting performance. This question is of particular importance in the present context, in which a linear relation between math anxiety and math cognition was no longer assumed. Therefore, our second aim in the current studies was to examine the potentially complex interaction between math anxiety and math motivation in relation to math cognition. Specifically, we investigated whether the quadratic relations between math anxiety and math performance would further vary as a function of math motivation. It is possible that while intermediate levels of anxiety can facilitate attention focusing and mobilization of cognitive resources, this facilitative effect of math anxiety on math performance may be observed only in individuals who are highly motivated to overcome challenges and relieve discomfort in math situations via active approach. To the contrary, the greater levels of fear and discomfort in individuals who are not motivated in math may be associated with more withdrawal of efforts, resulting in even poorer performance. Therefore, we hypothesized that the quadratic curvilinear relations between math anxiety and math performance would be observed only in individuals with high math motivation, whereas a negative linear relation would be observed in those with low math motivation. We tested our hypotheses in two independent samples.

Study 1

Method

Participants. Data were collected from 262 pairs of same-sex twins (58% female, 42% male) who participate in the ongoing longitudinal Western Reserve Reading and Math Projects (Hart, Petrill, Thompson, & Plomin, 2009). Annual assessments for these projects began in kindergarten or first grade and have continued across a maximum of 10 waves. The current study examined data collected when siblings were an average of 12.25 years old (*SD* = 1.20 years, range = 8.75–15.33). The race composition of the sample was 91% White, 5% African American, and 2% Asian. Parental education varied widely: 20% had some postgraduate education, 42% had a bachelor's degree, 16% had attended some college, 10% had a high school education or less, and 12% did not specify their level of education.

Procedure and measures. The current study was approved by the Office of Responsible Research Practices at The Ohio State University and the Case Western Reserve University Institutional Review Board. The current study included data collected on two separate 3-hr home visits that occurred within 1 month of each other. Parental consent and child assent were obtained at the beginning of each home visit. Each child was evaluated by a separate tester in a separate room on a series of cognitive assessments. In addition, children completed a series of questionnaires. Each family received a $100 honorarium for their participation in each visit.

Math anxiety. Children reported their own math anxiety using the revised Mathematics Anxiety Rating Scale for elementary students (MARS-E; Suinn, Taylor, & Edwards, 1988). The 26 items on the MARS-E are rated on a 5-point Likert-type scale (1 = *not at all nervous*, 5 = *very very nervous*) that captures how tense or worried children feel during math-related activities. The MARS-E has excellent internal consistency (Cronbach's α = .94).

General anxiety. The general-anxiety subscale of the Spence Children's Anxiety Scale (Spence, 1997) was used to measure children's general anxiety. This subscale consists of six items that are rated on a 4-point Likert-type scale (1 = *never*, 4 = *always*). This scale has adequate internal consistency (Cronbach's α = .71).

Math motivation. Children self-reported their math motivation using three items from the scale developed by M. M. Chiu and Zeng (2008). These items are rated on a 4-point Likert-type scale (1 = *strongly disagree*, 4 = *strongly agree*) and measure children's beliefs about the value of math as well as their interest in math. The Cronbach's α for this scale is .78, which indicates adequate internal consistency.

Math performance. Six tasks were used to assess participants' math performance. The dots task captures individual differences in the approximate number system by measuring an individual's ability to represent numerical quantities nonverbally (Halberda, Mazzocco, & Feigenson, 2008). The dots task was administered on a laptop. In this task, participants are shown a series of pictures of intermixed blue and yellow dots of different sizes and quantities. Participants have to decide whether there are more blue dots or yellow dots on each trial. The total number of dots in each trial was randomized between 5 and 16. Four possible ratio bins were presented across trials: 1:2, 3:4, 5:6, and 7:8. For each participant, two sessions were administered with 10 practice trials and 10 test trials per ratio bin per session. Participants' scores were expressed as Weber fractions, corrected for guessing, which were used as the outcome variable of interest. Larger Weber fractions represent less accurate nonsymbolic number estimation.

The number-line-estimation task captures individuals' ability to represent and estimate numerical quantities spatially (Siegler & Opfer, 2003). Participants are shown a series of blank number lines approximately 24 cm long with the label "0" at one end and "1,000" at the other end. Each blank number line is presented in the center of a separate piece of paper, together with a number above the line. Participants are asked to estimate where that number would be on the number line using a pencil mark. Participants were first given a practice trial in which they were asked to place "500" on the number line. Subsequently, 22 test trials were administered in the same order for all participants. To obtain the actual number represented by the mark given by each participant, we measured the length from "0" to the mark on the line, divided by the total length of the line, and multiplied by 1,000. To measure each participant's estimation accuracy, we obtained the average of the 22 absolute-difference scores between the participant's answers and the corresponding target numbers: This number was the outcome of interest. Larger scores represent less accurate symbolic number estimation.

The composing and decomposing numbers task (CDNT) is a timed measure of the automaticity of composing and decomposing numbers (Mazzocco & Hanich, 2010). The CDNT was administered using pencil and paper. Of the four blocks in this task, the first was a practice block in which participants were asked to compose as many numerical pairs as possible that sum to 19. In the second and third blocks, participants were presented with 49 pairs of numbers per block, and they were asked to circle the pairs that sum to 19. In these two blocks, 21 pairs of numbers summed to 19, and 28 pairs did not (i.e., foil pairs). In the fourth block, participants were asked to circle pairs of numbers that sum to 19 and cross out pairs that sum to more than 23, again among 49 pairs of numbers. There were 21 pairs of numbers that summed to 19 and 7 pairs that summed to more than 23. Participants were encouraged to work as quickly as possible without skipping, and they were given 60 s to work on each block. Response time was defined as the time between the start and the end of a block (a maximum of 60 s) and was recorded by the tester using a stopwatch. The number of correct responses was computed as the total circled pairs that summed to 19 and uncircled foil pairs evaluated in 60 s or less. In addition, pairs correctly crossed out were counted as correct responses for the fourth block. Efficiency scores were computed for each block by dividing the number of correct responses by response time (in seconds). A mean efficiency score was computed by averaging the efficiency scores across the last three blocks; this score was the outcome variable of interest for this task.

The problem-verification task was developed as a measure of calculation fluency and metacognition (Rinne & Mazzocco, 2014). We relied on the calculation-fluency component of this measure in the present study. On a laptop, participants were shown a series of two-operand arithmetic problems involving addition, subtraction, multiplication, division, and equivalency of fractions. For each arithmetic problem, a solution was shown that was correct or incorrect, and participants were asked to answer "right," "wrong," or "don't know" as quickly as possible without calculating. Participants were also asked to indicate whether they were "positively sure," "kind of sure," or "not sure" of their answer after each item. Each item was presented for a maximum of 10 s. If no response was given within that time, the program proceeded to the next item.

In total, participants were given 4 practice items followed by 88 test items. Among all test items, 64 were easy (e.g., single-digit arithmetic, common-denominator fraction, and solutions far from the correct answer), and 24 were hard (e.g., double-digit arithmetic, uncommon-denominator fraction, and solutions close to the correct answer). Reaction time (in seconds) was defined as the time between stimulus onset and response. For the current analyses, an efficiency score was calculated by dividing the percentage of total correct responses by the mean reaction time across all items.

The Calculation subtest of the Woodcock-Johnson III Tests of Achievement (Woodcock, McGraw, & Mather, 2001) is a measure of mathematical computation ability. This test was administered using paper and pencil. Participants were asked to solve a series of arithmetic problems. These arithmetic problems included addition, subtraction, multiplication, and division of positive and negative numbers, whole numbers, percentages, decimals, and fractions. Unlike the problem-verification task, the Calculation test is an untimed measure. It requires participants to do the actual calculation rather than to simply retrieve math facts. In addition, the complexity and difficulty level of the arithmetic problems in the Calculation test increases across items and far exceeds those in the problem-verification task. Scores were converted to *W* scores on the basis of item response theory (following the testing manual), and all scores have equal measurement intervals.

The Applied Problems subtest of the Woodcock-Johnson III Tests of Achievement (Woodcock et al., 2001) measures participant's ability to integrate math knowledge, quantitative reasoning, and calculation skills in problem solving. This test was administered using paper and pencil. Participants were shown a series of math story problems both orally and visually. Participants decided which mathematical operation to use and completed the calculations. *W* scores were computed in the same fashion as for the Calculation subtest.

Results

Descriptive and correlational analyses were conducted using SPSS (Version 22.0). Descriptive statistics are shown in Table 1. All main study variables were distributed widely across their respective scales. Most variables were distributed normally, with the exception of the dots task, number-line task, and problem-verification task. Subsequently, log transformations were performed on the skewed variables. Transformation successfully produced values that more closely approximated normal distributions. In addition, to maintain scale consistency across all math cognition tasks and to facilitate interpretation, we reversed-scored results from the dots task and number-line task so that higher scores also represented better performance.

Correlations between study variables are shown in Table 2. To account for the biased standard errors arising from sibling nonindependence, we adjusted significance tests for the correlations according to the method outlined by Griffin and Gonzalez (1995). Generally, math anxiety and math motivation did not differ as a function of child age. However, older children exhibited better performance on all math tasks, except for the dots task. Child sex (0 = female, 1 = male) was negatively associated with both general anxiety and math anxiety, which indicates higher general and math anxiety for girls than for boys. Boys outperformed girls on four out of six tasks, including number-line estimation, CDNT, problem verification, and Applied Problems. Additionally, general anxiety was minimally correlated with math-task performance,

Table 1. Descriptive Statistics for the Main Variables in Study 1

Variable	*n*	*M*	*SD*	Skewness	Kurtosis	Minimum	Maximum
General anxiety	391	5.42	2.78	0.61	0.42	0.00	15.00
Math anxiety	506	48.77	16.44	0.92	0.95	14.00	126.00
Math motivation	389	2.59	0.75	0.00	–0.43	1.00	4.00
Dots task	506	0.34	0.25	4.89	36.25	0.06	2.95
Number-line task	504	83.62	79.96	2.84	9.14	16.23	523.45
CDNT	511	0.48	0.20	0.78	0.98	0.11	1.31
Problem-verification task	505	16.41	6.71	1.12	2.65	2.82	55.63
Calculation test	493	518.98	16.62	–0.17	0.09	462.00	567.00
Applied Problems test	509	526.87	18.65	–0.26	1.58	449.00	597.00

Note: The *n*s for general anxiety and math motivation are lower than for the other variables because time constraints prevented these measures from being administered to all participants. CDNT = composing and decomposing numbers task.

whereas math anxiety was modestly negatively correlated with math performance. Math motivation was positively correlated with performance on the Calculation and Applied Problems tests, but was not correlated with performance on other math tasks. Finally, performance on all math tasks was positively correlated.

Subsequently, structural equation modeling with interchangeable dyads (Olsen & Kenny, 2006) using Amos (Version 22.0; SPSS) was employed to examine the two research questions. Structural equation modeling with interchangeable dyads was preferred over multiple regression because the former approach is more flexible, allowing the possibility of analyzing data from both siblings within the same family together to enhance statistical power while controlling for biased standard errors arising from sibling nonindependence at the same time (Olsen & Kenny, 2006).

Figure 1 presents the structural equation model with interchangeable dyads that was used to examine the first research question (whether math performance varies as a quadratic curvilinear function of math anxiety). Sibling data were organized in a pairwise fashion prior to model fitting such that each sibling was entered twice, once as Sibling 1 and once as Sibling 2. This model was symmetrically structured and contained two identical parts, one for Sibling 1 and one for Sibling 2. For each sibling, math performance was entered in the model as a manifest outcome. Child age and sex were the same for both siblings and thus were included only once in the model as statistical covariates. The linear and quadratic effects of general anxiety (i.e., general anxiety and its squared term) were entered as manifest covariates for each sibling to control for the possibility that the relations between math performance and math anxiety are due to general anxiety, not specific anxiety, about math. Finally, the linear and quadratic effects of math anxiety were entered as manifest predictors of math performance for each sibling. Additionally, parameters (means, variances, intercepts, regression weights, and correlations) for each sibling were constrained to be equal to their counterparts for the

Table 2. First-Order Correlations Between the Main Variables in Study 1

Variable	1	2	3	4	5	6	7	8	9	10
1. Age	—									
2. Sex	.07	—								
3. General anxiety	–.01	–.14*	—							
4. Math anxiety	–.04	–.19***	.38***	—						
5. Math motivation	–.11	.00	–.05	–.35***	—					
6. Dots task	.08	–.02	–.02	–.07	.05	—				
7. Number-line task	.32***	.19***	–.04	–.19***	.03	.23***	—			
8. CDNT	.39***	.21***	–.09	–.25***	.11	.21***	.40***	—		
9. Problem-verification task	.41***	.15**	–.14*	–.23***	.07	.10*	.33***	.59***	—	
10. Calculation test	.39***	.09	–.04	–.29***	.18**	.30***	.43***	.62***	.49***	—
11. Applied Problems test	.33***	.15**	–.10	–.33***	.20***	.33***	.56***	.64***	.47***	.70***

Note: CDNT = composing and decomposing numbers task.
*$p < .05$. **$p < .01$. ***$p < .001$.

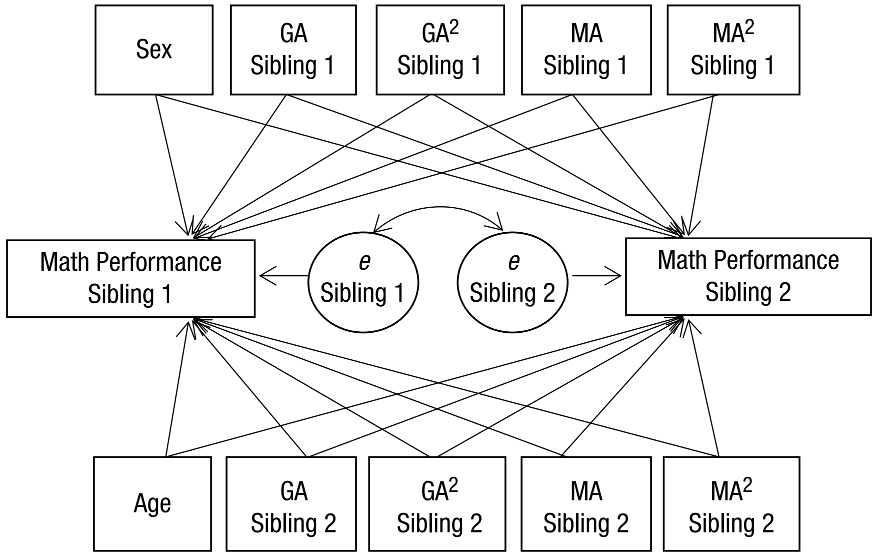

Fig. 1. Structural equation model of the linear and quadratic effects of math anxiety (MA) and general anxiety (GA) on math performance in members of same-sex twin pairs in Study 1. The correlations between covariates and predictors are not shown in the figure for clarity of presentation.

other sibling. Each math task was examined in a separate model, which resulted in six models. Note that math anxiety, math motivation, and general anxiety were standardized and centered prior to model fitting in order to compute the interaction and higher-order terms. All outcome variables were also standardized to maintain scale consistency and interpretability across all math tasks.

To estimate parameters as well as their confidence intervals, we bootstrapped 1,000 samples using the maximum-likelihood estimator for each model. To perform bootstrapping in Amos, we first replaced missing values in the data set using linear interpolation. Parameters and their bias-corrected 95% confidence intervals are reported in Table 3. Because there were various degrees of missing data, models were rerun using different methods of handling missing data in order to test for potential bias yielded by linear interpolation. Results remained essentially the same when missing data were handled using both listwise deletion and full-information maximum-likelihood estimation. Because these were all saturated models, chi-square values and degrees of freedom were all zero. As shown in Table 3, total variance (i.e., total R^2) explained by this set of predictors in each of the six tasks ranged from .02 to .25, with less variance explained in the dots and number-line tasks than in the other math tasks. After controlling for the effects of the covariates, we found that math anxiety was negatively associated with all tasks. In addition, controlling for the linear effects of math anxiety revealed that the quadratic term was significantly associated with performance on the problem-verification and Calculation tasks.

To further examine these two significant quadratic curvilinear relations, we conducted post hoc analyses using methods outlined by Aiken and West (1991). The relations between math anxiety and performance on the two math tasks were examined at different levels of math anxiety (i.e., 3, 2, and 1 *SD* below and above the mean, as well as at the mean; Table 4). Overall, math anxiety was increasingly negatively associated with math performance on these two tasks as levels of math anxiety increased, a pattern that was inconsistent with our prediction.

To examine whether the quadratic relations between math anxiety and math performance would be further moderated by math motivation, we added three more manifest predictors for each sibling in each of the original six models. These predictors included a linear effect of math motivation, an interaction term (Math Anxiety × Math Motivation), and a moderated quadratic interaction term (Math Anxiety^2 × Math Motivation). Results of these models are shown in Table 5. In addition to the original six predictors, math motivation was positively associated with all math tasks. After controlling for the covariates, linear effects of math anxiety and math motivation, and all lower-order interaction terms, we found that the moderated quadratic term was significantly related to four math tasks but not significantly related to the dots and number-line tasks. These significant moderated quadratic effects persisted with the sequential Bonferroni correction. Overall, the covariates as a set explained a major proportion of variance in these math outcome variables, whereas the main effects of math anxiety and math motivation and

Table 3. Results From Study 1: Math Anxiety as a Predictor of Math Performance on the Six Tasks

Predictor	Dots (total R^2 = .02)	Number line (total R^2 = .16)	CDNT (total R^2 = .24)	Problem verification (total R^2 = .23)	Calculation (total R^2 = .25)	Applied problems (total R^2 = .23)
			Covariates			
Age	0.07 [–0.01, 0.13]	0.29 [0.21, 0.35]**	0.35 [0.28, 0.42]**	0.36 [0.30, 0.42]***	0.35 [0.28, 0.42]**	0.29 [0.21, 0.36]**
Sex	–0.02 [–0.10, 0.05]	0.13 [0.07, 0.20]**	0.13 [0.07, 0.20]**	0.07 [0.00, 0.13]*	–0.00 [–0.07, 0.07]	0.07 [–0.00, 0.14]
General anxiety	–0.01 [–0.09, 0.06]	0.02 [–0.05, 0.09]	0.02 [–0.04, 0.07]	–0.01 [–0.08, 0.06]	0.06 [–0.02, 0.13]	0.05 [–0.01, 0.11]
General anxiety^2	–0.03 [–0.10, 0.03]	0.00 [–0.05, 0.06]	–0.03 [–0.08, 0.02]	–0.04 [–0.09, 0.02]	–0.00 [–0.06, 0.06]	–0.05 [–0.10, 0.00]
ΔR^2	.02	.13	.20	.20	.15	.13
			Main effect			
Math anxiety	–0.05 [–0.14, 0.05]	–0.13 [–0.19, –0.06]**	–0.18 [–0.25, –0.11]**	–0.10 [–0.17, –0.03]**	–0.23 [–0.31, –0.16]**	–0.29 [–0.34, –0.23]**
ΔR^2	.01	.02	.02	.02	.08	.10
			Quadratic curvilinear effect			
Math anxiety^2	–0.04 [–0.11, 0.03]	–0.03 [–0.13, 0.06]	–0.03 [–0.08, 0.03]	–0.11 [–0.17, –0.04]**	–0.09 [–0.16, –0.03]**	0.01 [–0.07, 0.09]
ΔR^2	.00	.00	.01	.01	.01	.00

Note: For each predictor, the table presents standardized parameter estimates with 95% confidence intervals in brackets. For each step, the change in variance explained by the model (R^2) is given. CDNT = composing and decomposing numbers task.
*p < .05. **p < .01. ***p < .001.

their interactive effect added only incrementally to the model's ability to predict math performance.

To further examine the four significant moderated quadratic effects, we recentered math motivation at low (i.e., 1 *SD* below the mean) and high (i.e., 1 *SD* above the mean) levels to examine the relations between math anxiety and math performance across a wide range of math anxiety (3 *SD*, 2 *SD*, and 1 *SD* above and below the mean as well as at the mean) at these two different levels of math motivation (Aiken & West, 1991). These results are shown in Table 6 and Figure 2. Overall, the findings were consistent with our prediction. At low levels of math motivation, math anxiety was modestly negatively associated with task performance across all levels of math anxiety. At high levels of math motivation, there was an inverted-U curvilinear relation between math anxiety and each of these four tasks, such that performance peaked at an intermediate level of math anxiety and decreased as levels of math anxiety deviated from this optimal intermediate level. However, compared with the other tasks, performance on the Applied Problems test peaked at relatively lower levels of math anxiety.

Given the complexity of the three-way interaction and the small effect sizes, we conducted a replication study in another sample (college students) in order to examine whether the moderated quadratic effect between math anxiety and math motivation on math cognition was replicable and generalizable to another developmental period.

Study 2 (Replication Study)

Method

Participants. Data were collected from 237 undergraduate students (56% female, 44% male) from The Ohio

Table 4. Study 1 Post Hoc Analyses: Statistical Predictive Effects of Math Anxiety on Math Performance at Different Levels of Math Anxiety

Task	Math-anxiety level: 3 *SD* below mean	2 *SD* below mean	1 *SD* below mean	*M*	1 *SD* above mean	2 *SD* above mean	3 *SD* above mean
Problem verification	0.09 [–0.06, 0.25]	0.03 [–0.10, 0.15]	–0.04 [–0.13, 0.05]	–0.10 [–0.17, –0.03]	–0.16 [–0.23, –0.11]	–0.23 [–0.30, –0.16]	–0.29 [–0.40, –0.20]
Calculation	–0.06 [–0.24, 0.10]	–0.12 [–0.26, 0.01]	–0.17 [–0.28, –0.08]	–0.23 [–0.31, –0.16]	–0.29 [–0.35, –0.23]	–0.34 [–0.40, –0.27]	–0.40 [–0.48, –0.30]

Note: The table presents standardized parameter estimates with 95% confidence intervals in brackets.

Table 5. Results From Study 1: Math Anxiety and Math Motivation as Predictors of Math Performance on the Six Tasks

Predictor	Dots (total R^2 = .03)	Number line (total R^2 = .18)	CDNT (total R^2 = .26)	Problem verification (total R^2 = .25)	Calculation (total R^2 = .28)	Applied problems (total R^2 = .27)
Covariates						
Age	0.07 [–0.00, 0.13]	0.30 [0.23, 0.37]**	0.36 [0.29, 0.43]**	0.37 [0.31, 0.43]***	0.36 [0.30, 0.43]**	0.31 [0.23, 0.39]**
Sex	–0.02 [–0.10, 0.05]	0.13 [0.06, 0.19]**	0.13 [0.07, 0.20]**	0.07 [0.00, 0.14]*	0.00 [–0.06, 0.07]	0.07 [–0.00, 0.14]
General anxiety	–0.02 [–0.09, 0.06]	0.02 [–0.05, 0.09]	0.01 [–0.05, 0.06]	–0.02 [–0.09, 0.05]	0.05 [–0.03, 0.11]	0.03 [–0.03, 0.09]
General anxiety^2	–0.03 [–0.10, 0.03]	0.01 [–0.05, 0.07]	–0.03 [–0.08, 0.02]	–0.04 [–0.10, 0.02]	–0.00 [–0.06, 0.06]	–0.04 [–0.08, 0.01]
ΔR^2	.02	.15	.21	.20	.15	.14
Main effects						
Math anxiety	–0.03 [–0.12, 0.05]	–0.12 [–0.19, –0.05]**	–0.14 [–0.23, –0.07]**	–0.06 [–0.13, –0.00]*	–0.18 [–0.26, –0.11]***	–0.24 [–0.31, –0.18]***
Math motivation	0.08 [0.00, 0.16]*	0.03 [–0.06, 0.12]	0.17 [0.10, 0.25]**	0.12 [0.05, 0.20]**	0.20 [0.13, 0.28]**	0.21 [0.14, 0.29]***
ΔR^2	.01	.02	.04	.02	.10	.10
Quadratic curvilinear effect and linear interaction effect						
Math anxiety^2	–0.04 [–0.11, 0.03]	–0.06 [–0.14, 0.04]	–0.04 [–0.10, 0.02]	–0.10 [–0.17, –0.01]*	–0.12 [–0.17, –0.05]**	–0.03 [–0.09, 0.04]
Math Anxiety × Math Motivation	0.02 [–0.06, 0.10]	–0.08 [–0.15, –0.02]*	0.07 [0.00, 0.15]*	0.14 [0.07, 0.22]**	0.08 [0.02, 0.15]*	0.02 [–0.04, 0.09]
ΔR^2	.00	.02	.00	.02	.01	.00
Moderated quadratic curvilinear effects						
Math Anxiety^2 × Math Motivation	–0.04 [–0.12, 0.05]	–0.04 [–0.13, 0.06]	–0.11 [–0.21, –0.03]**	–0.09 [–0.19, –0.01]*	–0.15 [–0.24, –0.06]**	–0.17 [–0.26, –0.07]**
ΔR^2	.00	.00	.01	.01	.01	.02

Note: For each predictor, the table presents standardized parameter estimates with 95% confidence intervals in brackets. For each step, the change in variance explained by the model (R^2) is given. CDNT = composing and decomposing numbers task.
*p < .05. **p < .01. ***p < .001.

Table 6. Study 1 Post Hoc Analyses: Statistical Predictive Effects of Math Anxiety on Math Performance at Different Levels of Math Anxiety and Math Motivation

Level of math anxiety	CDNT	Problem verification	Calculation	Applied problems
1 *SD* below mean of math motivation				
3 *SD* below mean	–0.26 [–0.51, –0.02]	–0.13 [–0.36, 0.10]	–0.22 [–0.44, 0.00]	–0.39 [–0.60, –0.15]
2 *SD* below mean	–0.24 [–0.44, –0.06]	–0.15 [–0.32, 0.03]	–0.23 [–0.40, –0.06]	–0.34 [–0.51, –0.16]
1 *SD* below mean	–0.22 [–0.37, –0.08]	–0.16 [–0.29, –0.03]	–0.24 [–0.37, –0.12]	–0.30 [–0.42, –0.17]
Mean	–0.20 [–0.30, –0.10]	–0.18 [–0.28, –0.09]	–0.25 [–0.34, –0.16]	–0.25 [–0.34, –0.16]
1 *SD* above mean	–0.18 [–0.24, –0.11]	–0.20 [–0.27, –0.13]	–0.25 [–0.33, –0.19]	–0.20 [–0.28, –0.14]
2 *SD* above mean	–0.16 [–0.22, –0.07]	–0.22 [–0.31, –0.14]	–0.27 [–0.36, –0.18]	–0.16 [–0.26, –0.08]
3 *SD* above mean	–0.14 [–0.24, –0.00]	–0.24 [–0.38, –0.13]	–0.27 [–0.42, –0.10]	–0.11 [–0.27, 0.01]
1 *SD* above mean of math motivation				
3 *SD* below mean	0.16 [–0.08, 0.40]	0.33 [0.07, 0.55]	0.31 [0.09, 0.53]	0.08 [–0.14, 0.27]
2 *SD* below mean	0.09 [–0.12, 0.27]	0.24 [0.04, 0.41]	0.17 [0.01, 0.35]	–0.01 [–0.18, 0.13]
1 *SD* below mean	0.01 [–0.14, 0.15]	0.15 [–0.00, 0.27]	0.04 [–0.08, 0.17]	–0.10 [–0.22, 0.01]
Mean	–0.07 [–0.18, 0.03]	0.05 [–0.06, 0.14]	–0.10 [–0.19, –0.01]	–0.19 [–0.28, –0.11]
1 *SD* above mean	–0.14 [–0.22, –0.07]	–0.04 [–0.13, 0.04]	–0.24 [–0.32, –0.16]	–0.28 [–0.36, –0.20]
2 *SD* above mean	–0.22 [–0.32, –0.14]	–0.14 [–0.24, –0.02]	–0.37 [–0.47, –0.29]	–0.37 [–0.47, –0.25]
3 *SD* above mean	–0.30 [–0.42, –0.18]	–0.23 [–0.36, –0.04]	–0.51 [–0.63, –0.38]	–0.46 [–0.60, –0.30]

Note: The table presents standardized parameter estimates with 95% confidence intervals in brackets. CDNT = composing and decomposing numbers task.

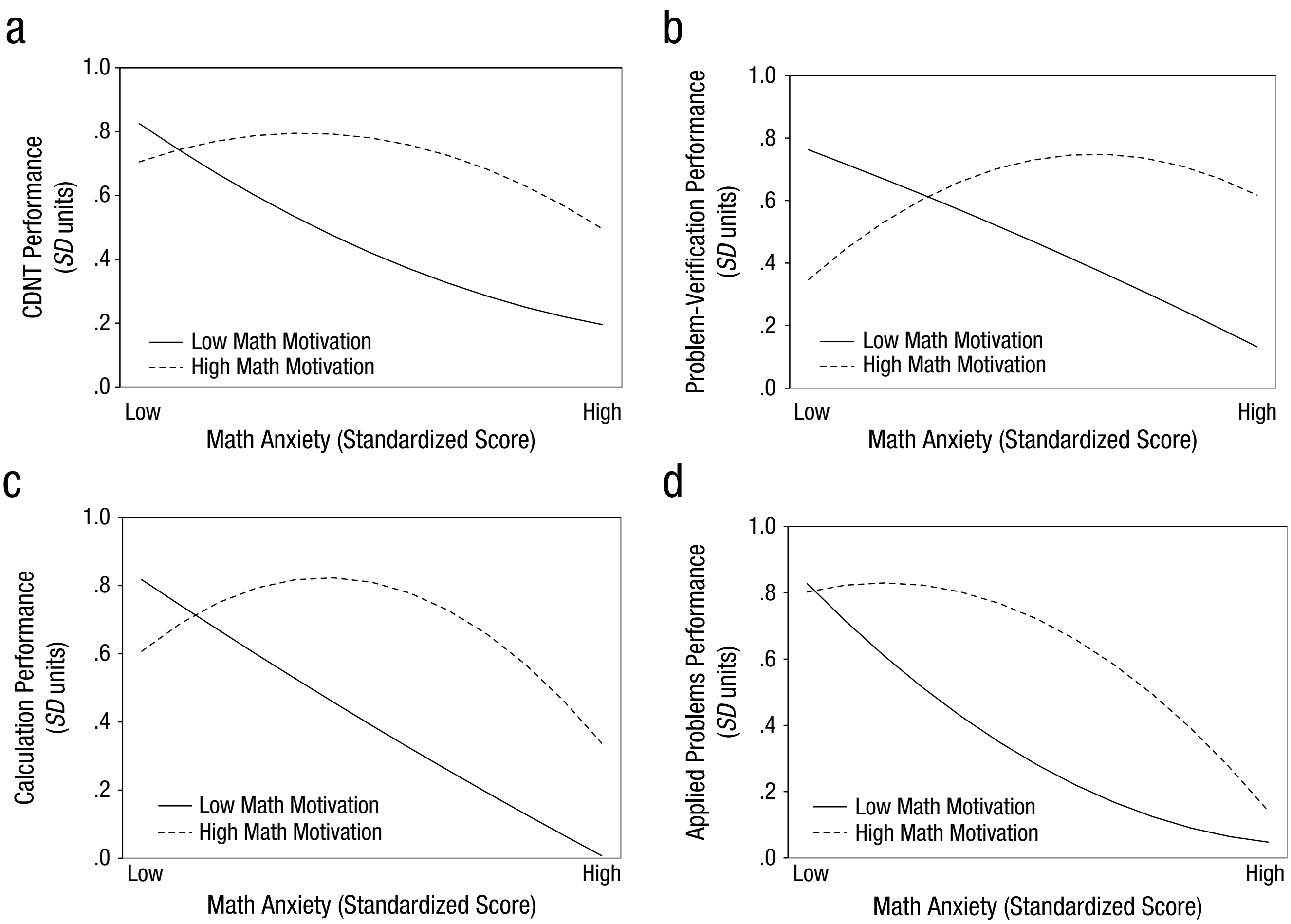

Fig. 2. Predicted math performance in Study 1 as a function of math anxiety and math motivation. Results are shown separately for performance on the (a) composing and decomposing numbers task (CDNT), (b) problem-verification task, (c) Calculation test, and (d) Applied Problems test. For math motivation, *low* and *high* refer to values 1 standard deviation below and above the mean, respectively.

State University using the online survey platform Qualtrics (2013). Undergraduate students taking an introductory psychology course were recruited on a voluntary basis and compensated with research credits. Eighteen participants were excluded from the analyses because of either technical problems (n = 2) or random responses (n = 16). Participants were on average 19.53 years old (SD = 2.01, range = 18–39). Participants' grade level varied: 57% freshman, 24% sophomore, 10% junior, and 8% senior. Participants were from diverse majors: 5% arts and humanities, 31% social sciences, 28% natural sciences, 13% engineering, and 12% premedicine; 12% were undecided. This study was approved by the Office of Responsible Research Practices at The Ohio State University.

Measures. Participants self-reported math anxiety using the brief version of the Mathematics Anxiety Rating Scale (MARS-B; Suinn & Winston, 2003). The 30-item MARS-B is widely used to measure math anxiety in adults. Items are rated are on a 5-point Likert-type scale (1 = *not at all nervous*, 5 = *very very nervous*). The MARS-B has excellent internal consistency (Cronbach's α = .94).

The trait subscale from the State-Trait Anxiety Inventory (Spielberger, 1983) was used to measure participants' general anxiety. This subscale consists of 20 items that are rated on a 4-point Likert-type scale (1 = *almost never*, 4 = *almost always*). This scale has excellent internal consistency (Cronbach's α = .94). Participants self-reported their math motivation using the same three items from the scale used in Study 1 (M. M. Chiu and Zeng, 2008). The Cronbach's α for this scale is .82, which indicates good internal consistency.

As in Study 1, the problem-verification task (Rinne & Mazzocco, 2014) was used to measure participants' math calculation fluency. Because the 64 easy items were far too easy for undergraduate students (mean accuracy = .93, SD = .06), we chose to focus on the 24 hard items. The hard items had wider performance

Table 7. Descriptive Statistics for the Main Variables in Study 2

Variable	*N*	*M*	*SD*	Skewness	Kurtosis	Minimum	Maximum
General anxiety	219	2.13	0.56	0.41	–0.42	1.05	3.55
Math anxiety	219	2.35	0.57	0.17	–0.02	1.00	4.03
Math motivation	219	3.09	0.92	–0.24	–0.46	1.00	5.00
Problem verification	219	0.20	0.06	–0.96	1.53	0.07	0.45

variability (mean accuracy = .85, *SD* = .13) and were therefore a more proper measure of individual differences in calculation fluency in college students. An efficiency score was obtained by dividing the percentage of total correct responses by the mean reaction time across all items.

Results

All analyses were conducted using SPSS (Version 22.0). Descriptive statistics are shown in Table 7. All main study variables were distributed widely and normally across their respective scales. Correlations between main study variables are shown in Table 8. None of these variables varied as a function of age. Sex (0 = female, 1 = male) was positively associated with performance on the problem-verification task and negatively correlated with math anxiety. Additionally, general anxiety was not related to math performance. Finally, math anxiety was negatively associated with math performance, whereas math motivation was positively associated with math performance.

Hierarchical regression analysis was used to examine whether the quadratic relation between math anxiety and math cognition was further moderated by math motivation. Specifically, performance on the problem-verification task was predicted in four steps. In Step 1, covariates including age, sex, and linear and quadratic terms of general anxiety were entered. The linear term of math motivation and math anxiety was entered in Step 2. In Step 3, we entered the quadratic term of math anxiety and the interaction between math anxiety and math motivation. Finally, we entered the moderated quadratic interaction term between math anxiety and math motivation in Step 4. Math anxiety, math motivation, and general anxiety were standardized and centered prior to analyses in order to compute the interaction and higher-order terms. The outcome variable was also standardized to maintain consistency across the two studies.

Results of the hierarchical regression analyses are shown in Table 9. Overall, age and sex both negatively predicted task performance, which indicates that younger and male participants performed better on average than older and female participants, with a larger effect size for sex than for age. General anxiety did not predict math performance. Math anxiety negatively predicted math performance after we controlled for the effects of the covariates. Finally, after controlling for all the linear and two-way interaction effects, we found that the moderated quadratic interaction between math anxiety and math motivation was statistically significant and added incremental predictive effects on math performance. To further examine the moderated quadratic effects, we conducted post hoc analyses on the predictive effects of math anxiety at different levels of math anxiety and math motivation using the same procedures as in Study 1. Results are shown in Table 10 and Figure 3. The findings were consistent with the results from Study 1. At low levels of math motivation, math anxiety was modestly negatively associated with task performance across all levels of math anxiety. At high levels of math motivation, there was an inverted-U curvilinear relation between math anxiety and math performance.

Table 8. Correlations Between the Main Variables in Study 2

Variable	1	2	3	4	5
1. Age	—				
2. Sex	–.13	—			
3. General anxiety	–.09	–.12	—		
4. Math anxiety	–.12	–.21**	.40***	—	
5. Math motivation	.09	.12	.00	–.28***	—
6. Problem-verification task	–.11	.34***	.02	–.19**	.10

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

Discussion

Research in the animal-learning and cognitive-psychology literatures has demonstrated that emotion and cognition are related in a complex fashion (Arnsten, 2009; Diamond et al., 2007). In the current studies, we extended this literature in the context of math performance by exploring the interplay between math anxiety and math motivation in relation to different types of math performance, and we demonstrated that the transactions between math-related emotions and cognitions were far more complex than simple linear and additive relations.

Consistent with our hypothesis, results showed that there was an inverted-U relation between math anxiety and math performance in students more intrinsically motivated in math, whereas a negative linear relation was

Table 9. Results From Study 2: Hierarchical Regression Analyses Predicting Performance on the Problem-Verification Task From Math Anxiety and Math Motivation

Predictor	Step 1	Step 2	Step 3	Step 4
Age	–0.10 [–0.19, –0.02]*	–0.11 [–0.19, –0.02]*	–0.11 [–0.19, –0.02]*	–0.10 [–0.18, –0.01]*
Sex	–0.73 [–0.98, –0.47]***	–0.67 [–0.92, –0.41]***	–0.67 [–0.92, –0.41]***	–0.61 [–0.87, –0.35]***
General anxiety	0.10 [–0.14, 0.34]	0.23 [–0.03, 0.49]	0.23 [–0.03, 0.49]	0.23 [–0.03, 0.49]
General anxiety^2	–0.03 [–0.13, 0.08]	–0.04 [–0.15, 0.07]	–0.03 [–0.14, 0.08]	–0.06 [–0.17, 0.05]
Math anxiety	—	–0.18 [–0.33, –0.04]*	–0.18 [–0.32, –0.03]*	–0.26 [–0.42, –0.10]**
Math motivation	—	0.02 [–0.11, 0.15]	0.02 [–0.11, 0.15]	0.13 [–0.03, 0.30]
Math anxiety^2	—	—	0.03 [–0.10, 0.17]	0.05 [–0.09, 0.18]
Math Anxiety × Math Motivation	—	—	–0.01 [–0.12, 0.10]	–0.04 [–0.16, 0.07]
Math Anxiety^2 × Math Motivation	—	—	—	–0.10 [–0.19, –0.01]*
ΔR^2	.14***	.03*	.00	.02*
ΔF	$\Delta F(4, 214) = 8.64$	$\Delta F(2, 212) = 3.66$	$\Delta F(2, 210) = 0.26$	$\Delta F(1, 209) = 5.18$

Note: The table presents unstandardized coefficients with 95% confidence intervals in brackets.
*$p < .05$. **$p < .01$. ***$p < .001$.

observed in those less motivated. This observation emerged among both adolescents and adults. Notably, this pattern was observed in the four math tasks that required generating or evaluating number combinations (i.e., CDNT, problem verification, Calculation, Applied Problems) but not in the symbolic and nonsymbolic number-estimation tasks (i.e., the dots and number-line tasks, respectively). It is possible that the math-specific affect-cognition transaction may function through enhancing or impairing general cognitive processes, such as executive attention and working memory, that are more likely to be engaged during computation. These executive skills are less involved in more primary mathematical abilities, such as those assessed in the number-estimation tasks (Geary, 2007).

Table 10. Study 2 Post Hoc Analyses: Statistical Predictive Effects of Math Anxiety on Math Performance at Different Levels of Math Anxiety and Math Motivation

Level of math anxiety	Problem-verification task
1 *SD* below mean of math motivation	
3 *SD* below mean	–0.49 [–1.02, 0.04]
2 *SD* below mean	–0.43 [–0.84, –0.02]
1 *SD* below mean	–0.37 [–0.66, –0.07]
Mean	–0.30 [–0.51, –0.10]
1 *SD* above mean	–0.24 [–0.42, –0.07]
2 *SD* above mean	–0.18 [–0.41, 0.05]
3 *SD* above mean	–0.12 [–0.44, 0.20]
1 *SD* above mean of math motivation	
3 *SD* below mean	0.23 [–0.21, 0.66]
2 *SD* below mean	0.08 [–0.22, 0.38]
1 *SD* below mean	–0.07 [–0.27, 0.14]
Mean	–0.21 [–0.43, –0.00]
1 *SD* above mean	–0.36 [–0.67, –0.05]
2 *SD* above mean	–0.51 [–0.96, –0.06]
3 *SD* above mean	–0.65 [–1.25, –0.05]

Note: The table presents unstandardized coefficients with 95% confidence intervals in brackets.

The general cognitive literature has shown that moderate levels of anxiety help focus attention and enhance working memory, whereas extremely high or low levels of anxiety are associated with insufficient cognitive resources allocated to the tasks (Arnsten, 2009; Diamond et al., 2007). The current findings indicate that in the specific context of math learning, an area in which students have abundant experiences and well-developed attitudes, the facilitative and debilitative effects of math anxiety on math performance vary not only across different levels of math anxiety, but also as a function of how motivated children are to perform well. It is only in students with high math motivation that moderate math anxiety facilitated performance. In individuals with lower math motivation, higher math anxiety consistently had a debilitative effect on math performance. This pattern potentially points to the importance of math motivation in mobilizing cognitive resources and regulating the effects of negative affect during math problem solving. Further, it is consistent with contemporary functional MRI research that highlights the links between brain activations involved in motivating behaviors and cognitive control in improving performance in math-anxious adults (Lyons & Beilock, 2012).

The four tasks that assessed higher levels of mathematical processing in the current studies were similar to those encountered in students' math classes and math tests. Thus, it is possible that the observed relations between math affect and math performance capture more than just the transient distribution of cognitive resources, but also reflect long-term transactions between math-related affect and math behaviors. Students with higher math motivation may be more willing to

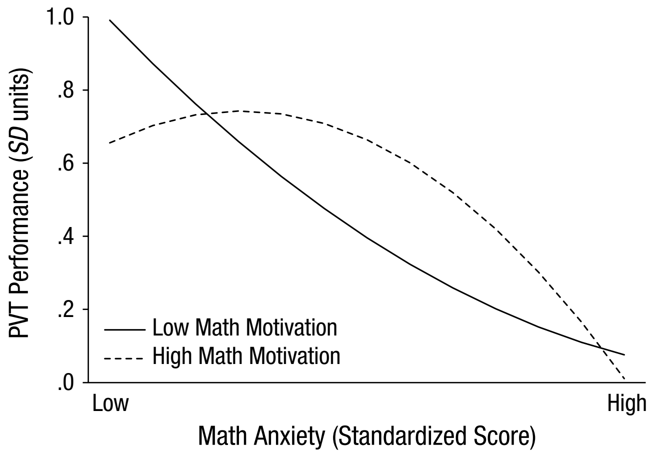

Fig. 3. Predicted performance on the problem-verification task (PVT) in Study 2 as a function of math anxiety and math motivation. For math motivation, *low* and *high* refer to values 1 standard deviation below and above the mean, respectively.

overcome math-related challenges via active approach (Middleton & Spanias, 1999; Vallerand et al., 1992). Therefore, it is possible that when students with high math motivation have intermediate levels of worry or discomfort during math activities, such challenges may motivate them to invest more effort, which leads to better math outcomes over time (Wigfield & Meece, 1988). On the contrary, given the avoidance tendencies in students who are not motivated in math (Middleton & Spanias, 1999), higher levels of negative affect and discomfort in situations involving math may push them further away from active engagement, which ultimately leads to poorer math outcomes. This possibility is in line with previous findings demonstrating that the effects of stress response on math performance depend on whether individuals interpret math situations as positive and challenging or negative and threatening (Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011).

Although such complex curvilinear relations were not found between math-related affect and performance on the two number-estimation tasks, math anxiety was negatively correlated with performance on the symbolic number-estimation task (number-line task), which suggests that poor math performance in highly math-anxious children may capture deficits in basic numerical processing beyond transient reduction in attentional and working memory resources (Núñez-Peña & Suárez-Pellicioni, 2014). In contrast, math anxiety was not related to the nonsymbolic number-estimation task (dots task). Because this task does not explicitly present numerical symbols, concepts, or operations, it is possible that such tasks are not particularly anxiety-provoking to math-anxious individuals.

Math learning is a prolonged and accumulative process. Given that the magnitude and etiology of the relations between math-related affect and cognition may differ across various developmental stages (Krinzinger et al., 2009), longitudinal studies spanning multiple developmental stages are needed to address how math anxiety and math motivation interact in relation to the development of math skills during daily math learning.

These findings should not be interpreted as evidence of a unidirectional causal relation between math-related emotion and math cognition. Rather, our goal was to explore the complex interplay between emotion and cognition in the context of math learning and to highlight potentially significant educational implications in improving math-learning experiences and outcomes. In particular, math anxiety may not universally impair the development of math abilities (Lyons & Beilock, 2012; Wigfield & Meece, 1988), and clinical efforts that simply aim to decrease math-anxiety levels may not prove effective for all students. The current findings suggest that moderate levels of math anxiety seem to be beneficial rather than detrimental to intrinsically motivated children. Therefore, it may be better for some students to maintain moderate levels of math anxiety, potentially through teachers making sure that learning and testing materials are moderately challenging. A combination of moderate math anxiety and high intrinsic motivation may help drive students to work harder in math learning and enjoy the fun in this process at the same time. These findings support math-education efforts to identify appropriate challenge levels for students by taking into account students' math-related abilities and affect.

Author Contributions

Z. Wang, S. A. Petrill, L. A. Thompson, and S. A. Hart designed the study and collected the data. Z. Wang analyzed the data and wrote the manuscript. S. L. Lukowski, S. A. Hart, I. M. Lyons, L. A. Thompson, Y. Kovas, M. M. M. Mazzocco, R. Plomin, and S. A. Petrill provided constructive criticisms throughout the development of the manuscript, as well as editorial feedback. All authors provided intellectual input and approved the final manuscript for submission.

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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