

Mathematics anxiety in young children: Concurrent and longitudinal associations with mathematical performance

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ABSTRACT

This study explored mathematics anxiety in a longitudinal sample of 113 children followed from second to third grade. We examined how mathematics anxiety related to different types of mathematical performance concurrently and longitudinally and whether the relations between mathematics anxiety and mathematical performance differed as a function of working memory. Concurrent analyses indicated that mathematics anxiety represents a unique source of individual differences in children's calculation skills and mathematical applications, but not in children's geometric reasoning. Furthermore, we found that higher levels of mathematics anxiety in second grade predicted lower gains in children's mathematical applications between second and third grade, but only for children with higher levels of working memory. Overall, our results indicate that mathematics anxiety is an important construct to consider when examining sources of individual differences in young children's mathematical performance. Furthermore, our findings suggest that mathematics anxiety may affect how some children use working memory resources to learn mathematical applications.

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1. Introduction

Mathematics anxiety refers to feelings of tension or worry that interfere with mathematical performance in daily life and school settings (e.g., Richardson & Suinn, 1972; Wigfield & Meece, 1988). Mathematics anxiety has consistently been found to have an inverse relation with mathematical performance, with correlations estimated between $-.27$ and $-.34$ for children across the middle and high school grades (Hembree, 1990; Ma, 1999). The negative impacts of mathematics anxiety have far-reaching consequences: compared to their less anxious peers, mathematically anxious students enjoy mathematics less, have lower perceptions of their mathematical abilities, and do not see the value of mathematics in everyday life (Ashcraft, Krause, & Hopko, 2007; Ashcraft & Moore, 2009; Hembree, 1990). Indeed, mathematically anxious students participate less in mathematics classes in middle school and steer away from mathematical majors (see Hembree, 1990; Meece, Wigfield, & Eccles, 1990). These patterns are particularly troubling given that mathematical proficiency is becoming increasingly important for full economic opportunity and meaningful participation in society (e.g., Moses & Cobb, 2001; Peterson, Woessmann, Hanushek, & Lastra-Anadón, 2011).

Although much has been learned about the development of mathematics anxiety, the vast majority of this extant research has focused on cross-sectional samples of fourth grade through college students (e.g., Baloghlu & Koçak, 2006; Birgin, Baloghlu, Catlioglu, & Gurbuz, 2010; Capraro, Capraro, & Henson, 2001; Newstead, 1998; Suinn, Taylor, & Edwards, 1988). For instance, from studies with older children and adults, we have learned that mathematics anxiety is a multi-dimensional construct, is distinct from both general and test anxiety, is not related to general intelligence, and appears to be a cause rather than simply a correlate of performance deficits (Ashcraft et al., 2007; Hembree, 1990; Ma, 1999). A major unresolved issue in the field concerns the early development of mathematics anxiety and whether there is practical utility in identifying mathematics anxiety-related behaviors in young children.

Although a few studies have begun to investigate mathematics anxiety in young children (i.e., Harari, Vukovic, & Bailey, in press; Krinzinger, Kaufmann, & Willmes, 2009; Ramirez, Gunderson, Levine, & Beilock, in press), there are mixed findings in this still new literature. For instance, Krinzinger et al. (2009) found that some first through third graders report mathematics anxiety-related characteristics—primarily worry—but this mathematics anxiety does not appear to relate to mathematical performance. By contrast, a study by Harari et al. (in press) suggests that other aspects of mathematics anxiety besides worry are indeed negatively related to mathematical performance in first graders. Finally, a study by Ramirez et al. (in press) suggests that mathematics anxiety in first and second graders may affect only those children with

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higher levels of working memory. Thus, the nature of mathematics anxiety in young children and its relation to mathematical performance—including over time—remains unspecified. Building on this research, the current study investigated the impact of mathematics anxiety on multiple mathematical outcomes, both concurrently and longitudinally, as well as examined whether this relation differed as a function of working memory.

1.1. The nature and assessment of mathematics anxiety

Considered a performance-based anxiety similar to social phobia and test anxiety, mathematics anxiety involves physiological arousal and negative cognitions both in the immediate context of a performance-based setting (e.g., math class) or in anticipation of having to perform (e.g., being called on during math class) and the potential for negative evaluation by either teachers or peers (Ashcraft et al., 2007; Hopko, McNeil, Zvolensky, & Eifert, 2001). Although the etiology of mathematics anxiety is unclear, the conception in the field is that mathematics anxiety results primarily from cumulative negative experiences in school as students encounter increasingly challenging mathematical material (e.g., Ashcraft et al., 2007; Beilock, Gunderson, Ramirez, & Levine, 2010; Geist, 2010). Indeed, in a meta-analysis, Hembree (1990) synthesized cross-sectional evidence suggesting that levels of mathematics anxiety increase from fifth grade throughout middle school, reaching peak levels in ninth and tenth grade, followed by a leveling off during later high school and college. This theory raises questions about whether young children who have had fewer experiences with mathematics by virtue of their age can experience the detrimental effects of mathematics anxiety. There is growing evidence that simple numerical tasks, such as counting and magnitude judgment, elicit mathematics anxiety in adults (Maloney, Ansari, & Fugelsang, 2011; Maloney, Risko, Ansari, & Fugelsang, 2010), suggesting that mathematics anxiety may have roots in early numerical abilities. Hembree's meta-analysis did not include studies of children younger than fifth grade because such studies did not exist at the time. Understanding the characteristics of mathematics anxiety in young children will therefore inform theoretical models about the nature, etiology, and treatment of mathematics anxiety.

Mathematics anxiety tends to be conceptualized—and subsequently operationalized—in one of two ways. The first considers mathematics anxiety as including two related aspects: numerical anxiety—the anxiety involved in using mathematics in ordinary life and academic situations; and mathematics test anxiety—the anxiety related to testing and evaluation in mathematics. The Mathematics Anxiety Rating Scale (MARS; Richardson & Suinn, 1972) is the prototype for examining numerical and test anxiety. Developed for use with adults, the MARS is a 98-item scale composed of brief descriptions of specific mathematical situations that may simulate anxiety in everyday situations (e.g., working on an income tax form) and academic test situations. Respondents rank each item on a 5-point scale ranging from “not at all anxious” to “very anxious,” with higher scores indicating greater anxiety. The original MARS has been adapted to include brief versions for use with adults (Suinn, 2003), adolescents in 7th–12th grade (Suinn & Edwards, 1982), and elementary children in fourth to sixth grade (Suinn et al., 1988). Across studies, the MARS and its descendants have been shown to be psychometrically sound across sex, grade, and ethnicity (for reviews see Ashcraft et al., 2007; Hembree, 1990; Ma, 1999). The MARS has informed the development of more recent measures of mathematics anxiety (e.g., Hopko, Mahadevan, Bare, & Hunt, 2003), and has been the basis for designing measures to assess mathematics anxiety in children below fourth grade in a few cases (e.g., Gierl & Bisanz, 1995; Ramirez et al., in press; Young, Wu, & Menon, 2012).

The second conceptualization considers mathematics anxiety as including the same aspects as general anxiety, namely, worry (i.e., a cognitive component including concerns with doing well in mathematics) and negative reactions (i.e., an affective component including feelings of fear, dread, nervousness, and unpleasant physiological reactions). Although not used in research as frequently as the MARS series, some measures have been developed to assess mathematics specific negative affect and worry, including the Math Anxiety Questionnaire (MAQ; Wigfield & Meece, 1988), the Fennema–Sherman Mathematics Attitudes Scales (Fennema & Sherman, 1976), and the Mathematics Anxiety Scale (Betz, 1978). Mathematics specific negative affect and worry have been examined in individuals from 6th through 12th grade both in the United States (e.g., Bai, Wang, Pan, & Frey, 2009; Ganley & Vasilyeva, 2011; Hoffman, 2010; Mulhern & Rae, 1998; Wigfield & Meece, 1988), as well as in international samples including China and Taiwan (Ho et al., 2000), Turkey (Birgin et al., 2010), and Germany (Krinzinger et al., 2009), providing a strong basis for considering affective and cognitive aspects in the assessment of mathematics anxiety in young children.

The biggest challenge with exploring mathematics anxiety in young children is that currently existing measures are designed for children at or above the fourth grade, while capturing some but not all relevant dimensions. Correspondingly, researchers studying mathematics anxiety in young children have begun to devise exploratory measures with mixed success. In one of the first studies conducted with young children, Krinzinger et al. (2009) examined the relation between mathematics anxiety and mathematical performance with a sample of German children followed from first through third grade. The authors devised a scale in which children were asked to consider their attitudes and emotions pertaining to seven different mathematics-related situations: mathematics in general, written calculations, mental calculations, easy calculations, difficult calculations, mathematics homework, and understanding during mathematics instruction. Children answered four different types of questions for each situation (“How good are you at: mathematics in general/written calculations/etc?” “How much do you like: mathematics in general/written calculations/etc?” “How happy or unhappy are you if you have problems with: mathematics in general/written calculations/etc?” “How worried are you if you have problems with mathematics in general/written calculations/etc?”). Children marked their response to each item on a 5-point scale, with different response options for each question type: check marks and crosses for “how good are you” questions; wasps and candies for “how much do you like” questions; happy and unhappy faces for “how happy or unhappy” questions; and worried and relaxed faces for “how worried” questions.

The authors found evidence for two factors in their scale: general mathematics-related attitudes (“how good are you” and “how much do you like” questions) and negative emotions and anxiety (“how happy or unhappy” and “how worried” questions) (Krinzinger et al., 2009). Although the scales were reliable (Cronbach's alpha reported between .83 and .91), neither factor was statistically related to mathematical performance—specifically calculation skills—indicating that mathematics anxiety in young children may not be related to mathematical performance, but also perhaps that the scale was not a comprehensive assessment of mathematics anxiety in young children. Krinzinger et al. (2009) speculated that their null results reflected a methodological limitation in their scale. Specifically, the authors suggested that the wording of their items was too indirect and hypothesized that physiological reactions such as high pulse or avoidance behavior might be better than assessing the cognitive aspect of mathematics anxiety.

Building on the findings of Krinzinger et al. (2009), we extended the assessment of mathematics anxiety in young children to include not only worry, but also negative reactions and numerical

anxiety (Harari et al., *in press*). We created a 12-item scale based on both the MARS-Elementary (Suinn et al., 1988) and the MAQ (Wigfield & Meece, 1988). Following the recommendation of Krinzinger et al. (2009), we asked children direct questions as opposed to requiring children to infer levels of anxiety based on pictorial representations. The scale was shown to be reliable (Cronbach's $\alpha = .70$) in a sample of first graders. Furthermore, we found evidence that mathematics anxiety predicted unique variance in calculation skills and in early number skills, such as skip counting, counting-on backward, and identifying number patterns. Our findings suggest that the null results reported by Krinzinger et al. (2009) reflected either that they assessed only calculation skills or that their scale tapped only attitudes and worry as opposed to including other aspects of mathematics anxiety. However, we did not control for other variables that have a well-established relation with mathematical cognition in young children, including general reading achievement (e.g., Grimm, 2008; Jordan, Kaplan, & Hanich, 2002), early numeracy (Murphy, Mazzocco, Hanich, & Early, 2007; Vukovic & Siegel, 2010), and working memory (e.g., Geary et al., 2009; Murphy et al., 2007). It is of considerable interest to determine whether mathematics anxiety contributes uniquely to the prediction of mathematical performance in light of the need to examine sources of mathematics difficulty not typically considered in the research on struggling mathematics learners (Fletcher, Denton, & Francis, 2005; Francis et al., 2005; Vukovic, 2012).

Simultaneous to our research, Ramirez et al. (*in press*) examined mathematics anxiety in a sample of 154 first and second graders. The authors developed an 8-item measure based on the MARS-Elementary (Suinn et al., 1988). Similar to the scale developed by Krinzinger et al. (2009), children responded to each item by indicating how they felt based on pictorial representations. Unlike other Likert-type scales traditionally used in mathematics anxiety research, Ramirez et al. used a scale that featured a nervous face on one end of the scale, a semi-nervous face in the middle of the scale, and a calm face at the other end of the scale. Based on where children indicated they fell on the continuum, the researchers derived a score out of 16, with responses closer to the nervous face indicating greater anxiety. The researchers found a relation between mathematics anxiety and mathematical performance—specifically applied mathematical problem solving—but only for children with high working memory scores. There was no relation between mathematics anxiety and mathematical performance for children with lower working memory scores. The authors speculated that mathematics anxiety primarily affects those children who rely more heavily on working memory resources when solving mathematical problems (as we discuss in more detail below). However, in light of the findings of Harari et al. (*in press*), an alternative possibility is that a global relation was not found because the mathematics anxiety scale tapped only numerical anxiety and/or that the authors considered only mathematical applications.

In summary, there are inconsistencies in the research with young children. The findings from Krinzinger et al. (2009) suggest that mathematics anxiety—primarily worry—in young children may not be related to mathematical performance—calculation skills specifically. By contrast, other research suggests that mathematics anxiety—primarily numerical anxiety—might affect only those children with higher levels of working memory (Ramirez et al., *in press*). Still other research suggests that the relation between mathematics anxiety and mathematical performance in young children depends on how both mathematics anxiety and mathematical performance are measured (Harari et al., *in press*). In the current study, we thus utilized a mathematics anxiety scale that collectively tapped several aspects of mathematics anxiety, we assessed several domains of mathematical performance, and we considered the potential moderating role of working memory.

1.2. Working memory and mathematics anxiety

Working memory is conceptualized as a limited resource cognitive system responsible for the temporary storage and processing of information in immediate awareness (Baddeley & Hitch, 1994). It is generally accepted that mathematics anxiety detrimentally impacts mathematical performance by disrupting working memory resources otherwise devoted to skill execution (Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Eysenck & Calvo, 1992; Miller & Bichsel, 2004; National Mathematics Advisory Panel [NMAP], 2008; Young et al., 2012). For instance, Ashcraft and Kirk (2001) found that adults with high levels of mathematics anxiety have fewer working memory resources available to complete mathematical tasks—even mathematical tasks as basic as counting and arithmetic involving carrying—suggesting that mathematics anxiety affects on-line processing of mathematical tasks.

There are contrasting hypotheses, however, regarding *who* is most susceptible to working memory disruption as a result of mathematics anxiety. One account posits that the higher the working memory capacity, the more cognitive resources an individual has to both manage anxiety-related thoughts and solve the mathematical task at hand (e.g., Ashcraft & Kirk, 2001; NMAP, 2008). Thus, the hypothesis is that individuals with higher working memory capacity are less susceptible to performance deficits as a result of co-opted working memory resources compared to individuals with lower working memory capacity. The evidence supporting this account has been obtained exclusively from adult studies (e.g., Ashcraft & Kirk, 2001; Miller & Bichsel, 2004). For instance, Miller and Bichsel (2004) found that for mathematically anxious adults, those with higher working memory capacity had higher mathematics scores (i.e., calculation skills and applied problem solving) compared to adults with lower working memory capacity. That this effect held only for visual-spatial working memory—there was no relation between verbal working memory and mathematics anxiety—suggests that mathematics anxiety may impact the visual-spatial working memory system specifically.

A competing account posits that individuals with greater working memory capacity are *more* susceptible to performance deficits as a result of working memory disruption (Beilock & Carr, 2005). Indeed, Beilock and colleagues (e.g., Beilock & Carr, 2005; Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011) have found that individuals who rely more heavily on working memory resources to solve mathematical problems—defined as those with high working memory scores—are specifically impaired when under pressure to complete mathematical problems, presumably because the anxiety induced by high pressure situations consumes the working memory resources usually devoted to skill execution. By contrast, the mathematical performance of individuals with low working memory scores is not detrimentally impacted by anxiety, presumably because these individuals do not rely as heavily on working memory resources to solve mathematical problems in the first place. Ramirez et al. (*in press*) have recently extended this finding to young children. Using moderation analyses, Ramirez et al. found that the typical inverse relation between mathematics anxiety and mathematical performance—applied problems specifically—only held for children with high working memory capacity (i.e., high scores on a digit span task). There was no relation between mathematics anxiety and applied problem solving for individuals with low working memory. It is worth noting that the working memory tasks used by Beilock and colleagues require numerical processing, which may confound the results considering that even basic numerical processing can elicit mathematics anxiety (e.g., Maloney et al., 2010, 2011). In addition, despite other strengths in the design of Ramirez et al. (*in press*), their mathematics anxiety scale had marginal reliability (α reported at .55), raising the need for replication.

1.3. Present study

The small body of mathematics anxiety research with young children has resulted in conflicting findings. To begin to build a unified understanding of mathematics anxiety in young children, the present study measured various aspects of mathematics anxiety, considered several indicators of mathematical performance, and examined the potentially moderating role of working memory. We examined these associations in a longitudinal sample of children followed from second to third grade while controlling for the effects of general reading achievement, early numeracy, and working memory.

Based on the literature reviewed, we expected mathematics anxiety to represent a unique source of individual differences in young children's mathematical performance. The literature differs, however, in its predictions about how mathematics anxiety affects mathematical performance. On the one hand, there is evidence for a relation between mathematics anxiety and different types of mathematical performance across children. A competing hypothesis predicts that mathematics anxiety affects only those with high working memory capacity. How either of these relations holds over time in young children is not yet known. We thus designed our study to answer two main questions:

- (1) Does children's mathematics anxiety in second grade explain unique variance in their concurrent mathematical performance after controlling for general reading achievement, early numeracy, and working memory? Does this relation differ as a function of working memory?
- (2) Does children's mathematics anxiety in second grade explain unique variance in their third grade mathematical performance after controlling for second grade mathematical performance, general reading achievement, early numeracy, and working memory? Does this relation differ as a function of working memory?

2. Method

2.1. Participants

This study occurred as part of a prospective longitudinal study designed to examine the developmental course and cognitive predictors of various mathematical abilities in a cohort of ethnically and linguistically diverse children in an urban context. The data reported in the present study were collected with 113 children (54 females) who participated in the study in second and third grade (mean age in first grade = 7 years, 10 months, $SD = 6$ months). The children attended two Title 1 schools in a large urban center in northeastern United States; 92.8% of the sample received free or reduced lunch. The schools used the same inquiry-based mathematics curriculum, which involves little teacher-directed instruction. Overall, participating children were 29.2% Black and 64.6% Hispanic, while 6.2% reported another race/ethnicity or did not report their race/ethnicity. Of the 113 children, 44 (38.9%) were native English speakers and 69 (61.1%) spoke another primary language at home: 56 (49.6%) spoke Spanish primarily at home while 13 children (11.5%) spoke one of three other languages at home (i.e., Arabic, French, and Punjabi). There were no sex, demographic, or language group differences in any of the means for study measures or in any of the predictive relations of interest.

2.2. Measures

All measures of mathematical performance were assessed in second and third grade. Mathematics anxiety, reading ability, early numeracy skills, and working memory were assessed in second grade.

2.2.1. Mathematics anxiety

A developmentally appropriate measure was created to assess mathematics anxiety in young children (see Harari et al. (in press) for items). Several criteria were established to guide the development of the instrument: (1) the scale had to be informed by the research base on mathematics anxiety; (2) the items had to be derived from validated measures that have been used with older children; (3) the items had to be accessible to young children; and (4) the scale had to be suitable for brief group administration.

Similar to the scale created by Ramirez et al. (in press), we adapted questions from the MARS-Elementary (MARS-E; Suinn et al., 1988). We also adapted items from the MAQ (Wigfield & Meece, 1988) in order to include items pertaining to negative reactions and worry. We generated an initial pool of 20 items. Unlike other scales of mathematics anxiety, some of the items had a positive valence (e.g., *I like being called on in math.*) whereas others had a negative valence (e.g., *I get nervous about making a mistake in math.*). Because we were working with young children, we deliberately designed the items in this way to encourage children to be thoughtful about their response to each statement instead of marking the same response option by rote.

These items were then discussed in semi-structured interviews with two children (one first grader and one second grader) not involved in the research project. The children were asked to read the items and comment on their understandability, the response options, and to elaborate on their thinking. Through this process, we were able to revise the items to better reflect children's colloquial speech. For example, instead of having one neutral category between the definitive responses of "yes" and "no," the children indicated a need for mixed response options that leaned positive and leaned negative. The children identified "kind of" and "not really" as responses that leaned positively and negatively, respectively, and were distinct from "yes" and "no". In addition, given the larger research context of the present study, we used this process to pare down the number of items to create a meaningful scale for young children suitable for brief group administration. For instance, it was apparent in the interviews with the two children that interpreting the negative reactions and worry items that were worded in the opposite valence was too complex for this age range (e.g., *I never worry about doing well in math.* vs. *I worry about doing well in math.*). We therefore eliminated such items. Our final scale consisted of 12-items, consistent with the recommendation for minimum number of items for measuring psychological constructs (e.g., Fabrigar, Wegener, MacCallum, & Strahan, 1999). It is worth noting that our negative reactions and worry items are worded consistently with other measures of mathematics anxiety, whereas the positive valence of the numerical anxiety items is a novel feature of mathematics anxiety scales.

Similar to other measures of mathematics anxiety, children are required to respond to each of the 12 statements in our tool using a Likert-type scale. Children indicate the degree to which they agree with each statement using the following scale: yes, kind of, not really, and no. We considered a pictorial format similar to that used by McKenna and Kear (1990, May) in their "Garfield" Elementary Reading Attitude Survey, an approach also used by Krinzinger et al. (2009) and Ramirez et al. (in press). In the end, consistent with the recommendation of Krinzinger et al., we surmised that interpreting pictorial expressions of anxiety might actually be more difficult for young children than asking direct questions, an assumption that was confirmed in our interviews with two children. Numerical values were assigned to each item so that higher scores consistently indicated greater anxiety. To standardize administration and reduce the reading demands, questions were read aloud to the children. Cronbach's alpha for the overall scale was .80. The correlation with the MARS-E in fourth grade is .48 ($p < .001$), providing evidence of convergent validity. The scale

was not significantly correlated with reading achievement ($r = -.17$, $p = .14$), providing evidence of discriminant validity.

2.2.2. Control variables

In order to obtain more accurate estimates and reduce the likelihood of spurious relations between mathematics anxiety and mathematical outcomes, we controlled for general reading achievement and early numeracy skills. We used the *Woodcock-Johnson Third Edition Research Edition (WJ-III RE; Woodcock, McGrew, & Mather, 1999)* Letter-word Identification test to measure general reading achievement. With this test, children identify and pronounce isolated letters (e.g., g, r) and words of increasing difficulty (e.g., cat, palm). The publisher reports reliability between .96 and .98. We used the *WJ-III Quantitative Concepts test (Woodcock, McGrew, & Mather, 2007)* to assess early numeracy skills. With this test, children count, identify numbers and concepts such as “first” and “last,” identify mathematics terms and formulae, and determine the next number in a series (e.g., ***15, 30, 45, ____). The publisher reports reliability between .86 and .93.

2.2.3. Working memory

In light of the findings of Miller and Bichsel (2004), we focused specifically on measuring visual-spatial working memory. We used the *Swanson Cognitive Processing Test (S-CPT)* visual matrix subtest (Swanson, 1996). With this test, children study an increasingly complex pattern of dots in a matrix for 5 s and answer a processing question about the matrix. Children then recreate the pattern on a blank matrix. Reliability is reported at .78.

2.2.4. Calculation skills

The Computation subtest of the *Stanford Diagnostic Math Test-Fourth Edition (SDMT-4; Harcourt Assessment, 1996)* was used to measure the degree to which students have mastered addition and subtraction facts and are able to use procedural computational skills to solve addition and subtraction problems, including those requiring regrouping. Children have 25 min to complete 20 grade-level questions presented in arithmetic notation. The publisher reports Kuder-Richardson Formula 20 reliability of .85 for the second grade assessment and .84 for the third grade assessment.

2.2.5. Mathematical applications

Three measures were selected to capture a range of mathematical applications: story problems, algebra, and data analysis/probability.

Drawn from previous research (e.g., Carpenter & Moser, 1984; Jordan & Hanich, 2000), the story problems task requires children to solve 15 brief problems (e.g., *Elvedin had 5 pennies and then Eve gave him 2 more pennies. How many pennies does Elvedin have now? Ali has 4 pennies and Spike has 9 pennies. How many more pennies does Ali need to have as many as Spike?*). Following the methodology of Fuchs et al. (2006), the experimenter reads each item aloud and students have 30 s to respond. Cronbach's alpha for this measure was .84 in second grade and .80 in third grade.

With the *KeyMath-Third Edition (KeyMath3; Connolly, 2007)* Algebra subtest, children work with number sentences (e.g., *Six plus some number equals ten. Point to the missing number.*), describe patterns and functions (e.g., *If each circle stands for the same number, and four circles equals 12, what number does one circle stand for?*), and represent mathematical relations (e.g., *Eight equals six plus what number?*). The publisher reports reliability at .78 for second and third graders.

With the *KeyMath3 Data Analysis and Probability* subtest (Connolly, 2007), children read and interpret tables (e.g., *Here is a table that shows the eye color of all the children in a classroom. How many children have blue eyes?*), interpret tally charts, (e.g., *Here is a tally of the animals in a zoo. Altogether, how many gorillas and giraffes are*

there?), and estimate quantities (e.g., *Look at this chart that shows the cost of toys. About how much does a toy airplane and a doll cost altogether?*). The publisher reports reliability at .80 for second graders and .84 for third graders.

In second grade, the story problem measure was strongly correlated with both algebra ($r = .64$, $p < .001$) and data analysis/probability ($r = .47$, $p < .001$), while algebra was also strongly correlated with data analysis/probability ($r = .60$, $p < .001$). We thus created a second grade weighted mathematical applications composite variable using principal components factor analysis. One factor was extracted, which accounted for 71.48% of the variance. The factor was well defined by the variables, with loadings ranging from .81 to .89. The variables were also well defined by this factor solution, with communality values ranging from .65 to .80. Cronbach's alpha for this composite reached .80.

Similarly, we created a third grade mathematical applications weighted composite variable also using principal components factor analysis. The story problems measure was strongly correlated with both algebra ($r = .51$, $p < .001$) and data analysis/probability ($r = .60$, $p < .001$), while algebra was also strongly correlated with data analysis/probability ($r = .67$, $p < .001$). One factor was extracted, which accounted for 72.81% of the variance. The factor was well defined by the variables, with loadings ranging from .82 to .89. The variables were also well defined by this factor solution, with communality values ranging from .67 to .79. Cronbach's alpha for this composite reached .81.

2.2.6. Geometry

Given that mathematics instruction for young children often includes the study of shape, we thought it valuable to also assess whether mathematics anxiety might have an impact on children's geometric reasoning, an outcome that has been neglected in previous research. With the *KeyMath3 Geometry* subtest (Connolly, 2007), children analyze, describe, compare, and classify two- and three-dimensional shapes (e.g., *Which shape doesn't belong in this group?*), solve problems involving the relation between two-dimensional and three-dimensional objects (e.g., *Which puzzle piece will fit into this hole?*), and use visualization and formulas to solve problems (e.g., *Which shape will have the most blue squares when filled completely?*). The publisher reports reliability at .81 for second graders and .73 for third graders.

2.3. Procedure

Assessments of the children occurred in the spring of second and third grade. To avoid the possibility that completing the mathematics anxiety scale would inappropriately influence children's performance on the second grade mathematical tasks, the mathematics anxiety scale was always administered last, consistent with the approach of Ramirez et al. (in press) and others (e.g., Gierl & Bisanz, 1995; Suinn et al., 1988). Research assistants conducted the assessments in the schools. Research assistants completed an intensive 4-h training workshop on standardized administration, which included demonstrating 100% accuracy during mock administrations. In addition, a school psychology doctoral student was available to answer questions and provide coaching where necessary throughout data collection.

3. Results

Descriptive statistics and correlations among the variables are shown in Table 1. As shown in the first column of the correlation matrix, mathematics anxiety scores were negatively correlated with Grade 2 SDMT-4 computation ($r = -.33$, $p < .001$), Grade 2 mathematical applications ($r = -.36$, $p < .001$), Grade 3 SDMT-4

computation ($r = -.28, p = .003$), and Grade 3 mathematical applications ($r = -.32, p = .001$); these correlation coefficients were in the expected range based on previous research (Hembree, 1990; Ma, 1999). Mathematics anxiety scores were not statistically correlated with *KeyMath-3* geometry scores in either second grade ($r = -.12, p = .23$) or third grade ($r = .11, p = .26$). Mathematics anxiety scores were also not correlated with *SCPT* visual matrix ($r = -.10, p = .42$), consistent with the findings of Ramirez et al. (in press).

3.1. Do children's mathematics anxiety scores in second grade explain unique variance in their concurrent mathematical performance after controlling for general reading achievement, early numeracy, and working memory? Does this relation differ as a function of working memory?

We assessed the relation between mathematics anxiety and mathematical performance in second grade through a series of regression analyses in which we controlled for general reading achievement, early numeracy, and working memory. As shown in the first column of Table 2, we compared a model that included only the controls (Model 1), a model with controls and mathematics anxiety (Model 2), and a model with controls, mathematics anxiety, and the working memory by mathematics anxiety interaction term (Model 3). All assumptions for regression analyses were met and diagnostic statistics indicated no problems with multicollinearity. The grade 2 results are presented in the second column of Table 2.

3.1.1. Calculation skills

After controlling for reading ($\beta = .19, t = 2.09, p = .04$; Note that all β s are standardized regression coefficients), early numeracy ($\beta = .32, t = 3.41, p = .001$), and working memory ($\beta = .12, t = 1.48, p = .14$), mathematics anxiety accounted for a unique amount of variance ($\beta = -.25, t = -3.21, p = .002$) in calculation skills. The working memory by mathematics anxiety interaction was not statistically significant ($\beta = -.20, t = -0.73, p = .47$).

3.1.2. Mathematical applications

After controlling for reading ($\beta = .22, t = 2.81, p = .006$), early numeracy ($\beta = .41, t = 5.29, p < .001$), and working memory ($\beta = .31, t = 4.85, p < .001$), mathematics anxiety accounted for a unique amount of variance ($\beta = -.21, t = -3.18, p = .002$) in the mathematical applications composite. The working memory by

Table 2

Proportion of variance in mathematical outcomes by control variables, mathematics anxiety, and mathematics anxiety by working memory interaction.

Mathematical outcome	Grade 2 R^2_{change} value	Grade 3 R^2_{change} value
<i>SDMT-4 computation</i>		
Model 1: control variables	.295***	.267***
Model 2: mathematics anxiety	.061**	.017
Model 3: MA * WM interaction	.003	.018
<i>Mathematical applications</i>		
Model 1: control variables	.521***	.542***
Model 2: mathematics anxiety	.041**	.009
Model 3: MA * WM interaction	.001	.021*
<i>KeyMath-3 geometry</i>		
Model 1: control variables	.291***	.323***
Model 2: mathematics anxiety	.000	.000
Model 3: MA * WM interaction	.002	.000

Note: Control variables and mathematics anxiety were always measured at second grade. For Grade 2 analyses, controls included reading achievement, early numeracy, and the main effect of working memory. For Grade 3 analyses, controls including the corresponding Grade 2 mathematics performance outcome (i.e., the autoregressor), reading achievement, early numeracy, and the main effect of working memory. MA = mathematics anxiety. WM = working memory.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

mathematics anxiety interaction was not statistically significant ($\beta = -.13, t = -0.56, p = .58$).

3.1.3. Geometry

After controlling for reading ($\beta = .24, t = 2.45, p = .016$), early numeracy ($\beta = .26, t = 2.64, p = .01$), and working memory ($\beta = .26, t = 3.14, p = .002$), mathematics anxiety did not account for unique variance ($\beta = .00, t = 0.33, p = .97$) in children's geometry scores. The working memory by mathematics anxiety interaction was not statistically significant ($\beta = .16, t = 0.55, p = .59$).

3.2. Do children's mathematics anxiety scores in second grade explain unique variance in their third grade mathematical performance, controlling for second grade mathematical performance, general reading achievement, early numeracy, and working memory? Does this relation differ as a function of working memory?

To assess whether children's mathematics anxiety scores in second grade predicted mathematical performance in third grade, we

Table 1

Means, standard deviations, and correlations among variables for the full sample ($N = 113$).

Variable	M (SD)	Correlations							
		1	2	3	4	5	6	7	8
1. Mathematics anxiety	22.02 (7.95)	–							
2. <i>WJ-III</i> Letter-word identification	102.98 (12.91)	–.17	–						
3. <i>WJ-III</i> Quantitative Concepts	90.23 (13.24)	–.22*	.55***	–					
4. <i>SCPT</i> Working memory	7.23 (2.70)	–.08	.15	.12	–				
5. Grade 2 <i>SDMT-4</i> computation	556.70 (48.01)	–.32***	.43***	.45***	.20*	–			
6. Grade 2 Mathematical applications	0.00 (1.00)	–.36***	.52***	.61***	.41***	.57***	–		
7. Grade 2 <i>KeyMath-3</i> geometry	6.52 (2.40)	–.12	.42***	.42***	.32***	.34***	.56***	–	
8. Grade 3 <i>SDMT-4</i> computation	595.53 (50.68)	–.28**	.40***	.40***	.19*	.43***	.44***	.30**	–
9. Grade 3 Mathematical applications	0.00 (1.00)	–.32***	.48***	.54***	.30**	.72***	.49***	.64***	.64***
10. Grade 3 <i>KeyMath-3</i> geometry	8.72 (2.29)	–.11	.33***	.34***	.32**	.32***	.54***	.52***	.27**

Note: Mathematics anxiety is presented in raw scores and mathematical applications is presented in z-scores. All other measures are presented in standardized scores based on national norms. *WJ-III* scores are standard scores (mean = 100; $SD = 15$). *SCPT* and *KeyMath-3* scores are scaled scores (mean = 10, $SD = 3$). *SDMT-4* scores are extended scaled scores.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

conducted a series of regression analyses in which we controlled for the autoregressor, i.e., the relevant second-grade mathematics variable. We also controlled for general reading achievement, early numeracy, and working memory in second grade. All assumptions for regression analyses were met and diagnostic statistics indicated no problems with multicollinearity. Results are presented in the third column of Table 2.

3.2.1. Calculation skills

After controlling for second grade reading ($\beta = .20$, $t = 1.98$, $p = .05$), early numeracy ($\beta = .14$, $t = 1.39$, $p = .17$), working memory ($\beta = .09$, $t = 1.12$, $p = .27$), and SDMT-4 computation ($\beta = .20$, $t = 2.00$, $p = .048$), mathematics anxiety did not account for unique variance ($\beta = -.14$, $t = -1.61$, $p = .11$) in third grade calculation skills. The working memory by mathematics anxiety interaction was not statistically significant ($\beta = -.49$, $t = -1.65$, $p = .10$).

3.2.2. Mathematical applications

After controlling for second grade reading ($\beta = .11$, $t = 1.35$, $p = .18$), early numeracy ($\beta = .12$, $t = 1.42$, $p = .16$), working memory ($\beta = .05$, $t = 0.64$, $p = .53$), and mathematical applications ($\beta = .53$, $t = 5.44$, $p < .001$), mathematics anxiety did not account for unique variance ($\beta = -.10$, $t = -1.45$, $p = .15$) in third grade mathematical applications. The working memory by mathematics anxiety interaction was statistically significant ($\beta = -.52$, $t = -2.26$, $p = .026$), indicating that the relation between mathematics anxiety and mathematical applications depended on working memory.

Fig. 1 plots the predicted mathematical applications scores of children who are performing at, 1 standard deviation above, and 1 standard deviation below the sample mean for working memory. As shown, there was a pronounced negative relation between mathematics anxiety and mathematical applications for children with above-average working memory scores, and a slight positive effect for children with below-average working memory scores. To investigate whether these relations were significant at these three different levels of working memory, we conducted post hoc analyses by centering the working memory variable and corresponding interaction term at different values, while centering the control variables and mathematics anxiety at the sample mean. These analyses indicated that the stronger negative relation between mathematics anxiety and mathematical applications for stu-

dents with above-average working memory was statistically significant ($\beta = -.25$, $t = -2.64$, $p = .01$), that the negative relation between these variables was not statistically significant for students with sample-average working memory ($\beta = -.09$, $t = -1.37$, $p = .17$), consistent with Model 2, and that the slight positive relation between these variables for students with below-average working memory was not statistically significant ($\beta = .06$, $t = 0.64$, $p = .52$).

3.2.3. Geometry

After controlling for second grade reading ($\beta = .09$, $t = 0.90$, $p = .37$), early numeracy ($\beta = .10$, $t = 1.00$, $p = .32$), working memory ($\beta = .17$, $t = 2.01$, $p = .047$), and geometry scores ($\beta = .39$, $t = 4.11$, $p < .001$), mathematics anxiety did not account for unique variance ($\beta = -.02$, $t = -0.23$, $p = .82$) in third grade geometry. The working memory by mathematics anxiety interaction was not statistically significant ($\beta = .07$, $t = 0.24$, $p = .81$).

4. Discussion

This study examined mathematics anxiety in a diverse sample of children followed from second to third grade. Previous research suggests that as children move throughout their academic career, levels of mathematics anxiety increase, reaching peak levels around ninth grade (see Hembree, 1990) and continuing into adulthood (Baloğlu & Koçak, 2006; Capraro et al., 2001; Miller & Bichsel 2004). Far less is known, however, about how mathematics anxiety relates to mathematical performance for children below fourth grade, and the extant research has produced mixed findings. Building on this research, our findings revealed that mathematics anxiety represents a unique source of individual differences in children's calculation skills and mathematical applications, consistent with Harari et al. (in press), but not in children's geometric reasoning. Furthermore, using longitudinal auto-regression analyses, we found that higher levels of mathematics anxiety contributed to lower gains in children's mathematical applications, but only for children with higher levels of visual-spatial working memory, providing converging evidence for the hypothesis raised by Ramirez et al. (in press). In this discussion we elaborate more specifically on these key findings.

4.1. Mathematics anxiety is a robust source of individual differences in children's mathematical performance

In this study, mathematics anxiety scores were negatively correlated to calculation skills and mathematical applications in both second and third grade. In regression analyses controlling for general reading achievement, early numeracy, and working memory, mathematics anxiety contributed unique variance to both calculation skills and mathematical applications concurrently, but not longitudinally after controlling for the autoregressor. Mathematics anxiety scores were not related to children's geometric reasoning concurrently or longitudinally. Two main insights emerge from these findings.

First, our findings that the negative relation between mathematics anxiety and mathematical performance held even after controlling for reading ability, working memory, and early numeracy—constructs that have well-established relations with mathematics performance in young children (e.g., Geary et al., 2009; Jordan et al., 2002; Murphy et al., 2007)—provides more robust evidence than previously reported of the strength of the relation between mathematics anxiety and mathematical performance. These findings support recent calls to broaden our lens on potential sources of children's mathematical difficulties (Fletcher et al., 2005; Francis et al., 2005; Vukovic, 2012). Our results indicate that alongside

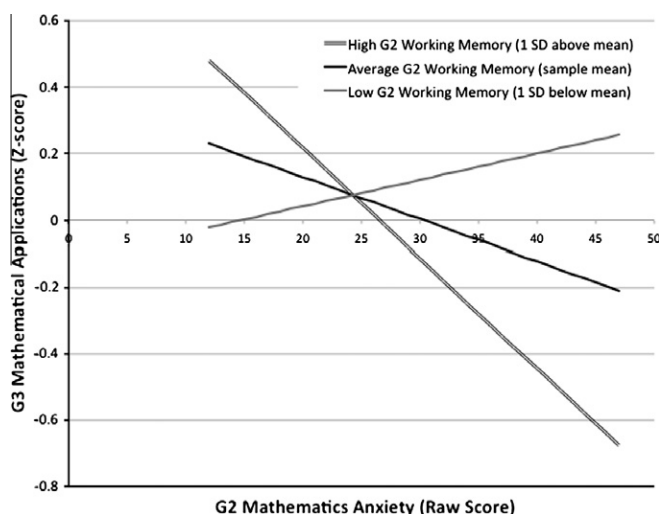


Fig. 1. Fitted relation between Grade 3 (G3) mathematical applications and Grade 2 (G2) mathematics anxiety for prototypical cases with high, average, and low Grade 2 working memory, based on Model 3, which included controls for Grade 2 mathematical applications, reading achievement, early numeracy, and the main effect of working memory.

variables such as working memory and early numeracy, mathematics anxiety is an important construct to consider when examining sources of individual differences in young children's mathematical performance.

Second, our findings suggest that mathematics anxiety does not affect all types of mathematical performance equally. Specifically, mathematics anxiety uniquely predicted children's calculation skills and their mathematical applications, but not their geometric reasoning. What might underlie this difference? Calculation skills and mathematical applications have in common that they are both based in the symbolic number system—that is, the number and quantitative skills that depend on the formal number system (Jordan, Glutting, & Ramineni, 2010; LeFevre et al., 2010). By contrast, the geometry measure requires children to solve problems involving spatial and attribute relations—in other words, problems that do not involve numbers. The results thus indicate that mathematics anxiety may specifically affect mathematical problems that involve understanding and manipulating numbers. This appears to be the case whether the mathematical problems are presented in standard arithmetic notation or within scenarios that do not necessarily include formal mathematical conventions. By contrast, we found little evidence that mathematics anxiety related to children's geometric reasoning, at least at second and third grade. It may be the case that young children do not consider the study of shapes to be mathematics, or, alternatively, geometry in the younger grades may not be difficult enough to trigger mathematics anxiety. It might also be the case that our mathematics anxiety measure did not capture geometry-specific anxiety. Ramirez, Gunderson, Levine, and Beilock (2012) found that children as young as second grade, especially girls, do report experiencing spatial anxiety. The extent to which such spatial anxiety relates to mathematics anxiety and more importantly, how it impacts children's mathematical performance—geometric or otherwise—remains to be determined.

4.2. Mathematics anxiety may impede the learning of mathematical applications for children with higher working memory

Beilock and colleagues (e.g., Beilock & Carr, 2005; Mattarella-Micke et al., 2011) have proposed that mathematics anxiety specifically affects individuals with higher working memory scores, presumably because their anxiety consumes working memory resources usually devoted to skill execution. Beilock and colleagues refer to this phenomenon as the “choking” effect, in that individuals who are otherwise capable “choke” under pressure. Replicating this finding with young children, Ramirez et al. (in press) found that mathematics anxiety predicted mathematical performance—mathematical applications specifically—only in children with higher levels of working memory. They did not find a relation between mathematics anxiety and mathematical applications in children with lower levels of working memory. In the cross-sectional analyses of the current study, we were not able to replicate the choking effect for any type of mathematical outcome. We did, however, replicate the finding in our longitudinal analyses: for children with higher working memory scores, there was a pronounced negative relation between second grade mathematics anxiety and third grade mathematical applications, even after accounting for second grade control variables—including the autoregressive effect of second grade mathematical applications. By contrast, there was no effect of second grade mathematics anxiety on third grade mathematical applications for children with low working memory scores. These results suggest that mathematics anxiety impairs the learning of mathematical applications specifically, particularly for children with higher working memory scores. Thus, mathematics anxiety appears to serve as a greater barrier to learning for some children than for others.

Building on the findings of Ramirez et al. (in press), our findings suggest that the “choking” effect in young children holds only for mathematical applications and exhibits its influence as a learning effect rather than a performance effect. That is, in real-time, mathematics anxiety may impact the mathematical performance of children with low or high working memory capacity equally. Over time, however, the anxiety that some children with higher working memory experience when confronting mathematical applications may become a barrier to learning, whereas children with lower levels of working memory alongside high levels of mathematics anxiety remain able to benefit from instruction (or at least their anxiety does not block their learning). As a result, children with higher levels of both working memory and mathematics anxiety may learn less mathematical applications over time.

Why might this be the case? Basic arithmetic problems are more noticeably right or wrong, whereas mathematical applications, by their nature, offer no direct routes to backup procedures for problem solution. Thus, it might be that mathematics anxiety impacts children's performance on both types of mathematical tasks, but the anxiety induced by arithmetic problems does not have lasting effects, in part because children can more easily identify and subsequently rectify any errors. In other words, children can rely on backup strategies to solve arithmetic problems and once the problem is solved, the effects of the anxiety subside. By contrast, the anxiety evoked by confronting mathematical applications might have lingering effects specifically because there are not any obvious cues to incorrect responses or backup procedures that children can use to solve these problems. This lingering anxiety appears to present future obstacles to learning specifically for children with higher working memory capacity. In other words, the anxiety induced by these intentionally ambiguous tasks prevents problem solving specifically for children with higher working memory, but may not affect how students with lower working memory solve these problems. Indeed, others have found that worry and anxiety actually thwart successful social problem solving in young children (e.g., Wilson & Hughes, 2011) and adults (e.g., Davey, 1994), because these individuals tend to endorse avoidant solutions as opposed to prosocial solutions. In conjunction with the current study, we speculate that children with higher levels of mathematics anxiety and higher levels of working memory do not differ from their peers with lower levels of working memory in their ability to generate effective solutions, but they are more likely to endorse avoidant solutions. Future research is needed to examine these hypotheses.

These findings also have important educational implications. Specifically, the findings suggest that although mathematics anxiety affects real-time performance equally for children with different levels of working memory capacity, mathematics anxiety differentially affects how children with different levels of working memory are able to profit from instruction. That is, children with higher levels of mathematics anxiety and working memory are at-risk for poor performance on mathematical applications over time, whereas their counterparts with lower levels of working memory do not suffer from such risk. Thus, exposure to mathematical applications without some form of instructional relief (e.g., providing problem solving heuristics) might be detrimental to some children. This implies that there is a group of children who will need more teacher support to learn mathematical applications than is often advocated in inquiry-based mathematics classrooms. For instance, effective instruction for struggling mathematics learners includes instructional explicitness, a strong conceptual basis, cumulative review and practice, and motivators to help maintain student interest and engagement (Fuchs et al., 2008; Gersten et al., 2009). This type of facilitated mathematics instruction that emphasizes mathematical thinking through explicit instruction and teacher scaffolding is gaining consensus by both mathe-

mathematics educators and special educators as critical elements of high quality mathematics instruction (Fuchs et al., 2008; Fuson, 2009; Gersten et al., 2009; Vukovic, 2012). Future research is needed to more definitively determine the role that instruction plays in alleviating children's mathematics anxiety and/or supporting the mathematical development of children who are highly mathematically anxious.

4.3. Limitations and future directions

This study has some limitations that raise questions for future research. First, although research with older learners suggests that mathematics anxiety is distinct from general anxiety and test anxiety (see Hembree, 1990), the nature of this relation in young children is unspecified. Thus, including measures of general anxiety and anxiety in other domains—including spatial anxiety—in future studies with young learners is necessary to investigate the extent to which mathematics anxiety is specific to mathematics and to examine its relation to other forms of anxiety at this developmental stage. Second, future research should focus on discerning the dimensionality of mathematics anxiety in young children. We were unable in the current study to examine different dimensions of mathematics anxiety separately because the positive and negative valence of our items was confounded with item type (as described in the methods section). Thus, future research should consider refining existing measures to balance the valence across item type, for instance by including matched items such as *I never worry when I am in math class* and *I often worry when I am in math class*. In so doing, such studies should be careful to account for the cognitive complexity of the items for young children, a concern which drove the design of the items in our scale. Future research is also needed to resolve whether separate dimensions of mathematics anxiety differentially impact the specific domains of mathematical cognition assessed in this study as well as other mathematical competencies not previously studied, including conceptual understanding and fractions. Finally, although this study included longitudinal findings and autoregressive analyses, such analyses remain correlational, raising the need for experimental research.

4.4. Conclusion

There is a growing body of research demonstrating that mathematics anxiety has its roots in early childhood. Our findings suggest that mathematics anxiety may detrimentally affect not only how young children perform mathematically, but also *how much* mathematics some children learn. This makes it even more critical that children are adequately supported in managing their anxiety while developing their skills in solving mathematical applications—especially in classrooms that emphasize inquiry-based approaches to learning mathematics over other approaches that may offer children more scaffolds to learning. That the detrimental effects of mathematics anxiety can be detected in the early childhood years underscores the importance of understanding sources of children's mathematics anxiety in order to intervene *before* children experience the negative consequences associated with consistent and repeated feelings of tension and worry towards mathematics.

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