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On the relationship between math anxiety and math achievement in early elementary school: The role of problem solving strategies

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A R T I C L E I N F O

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A B S T R A C T

Even at young ages, children self-report experiencing math anxiety, which negatively relates to their math achievement. Leveraging a large dataset of first and second grade students' math achievement scores, math problem solving strategies, and math attitudes, we explored the possibility that children's math anxiety (i.e., a fear or apprehension about math) negatively relates to their use of more advanced problem solving strategies, which in turn relates to their math achievement. Our results confirm our hypothesis and, moreover, demonstrate that the relation between math anxiety and math problem solving strategies is strongest in children with the highest working memory capacity. Ironically, children who have the highest cognitive capacity avoid using advanced problem solving strategies when they are high in math anxiety and, as a result, underperform in math compared with their lower working memory peers.

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Introduction

Early quantitative skills, including the ability to perform basic arithmetic operations and to fluently use a variety of problem solving strategies, are important to children's future success in the classroom (Clements & Sarama, 2011; Duncan et al., 2007; Geary, 2013; Hiebert & Carpenter, 1992; National Mathematics Advisory Panel, 2008; Star & Rittle-Johnson, 2009). Although young children vary in the problem solving strategies they use to solve arithmetic problems (Carr, Hettinger-Steiner, Kyser, & Biddlecomb, 2008; Jordan, Huttenlocher, & Levine, 1994; Jordan & Levine, 2009; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2011), we know little about the affective factors that may contribute to this variation. In a large field study, we show, for the first time, that first and second graders' math anxiety (i.e., a fear or apprehension about math) negatively predicts their use of advanced problem solving strategies, which in turn relates to their math achievement. This work opens a new window into understanding the interplay between affective factors and performance in mathematics in young children.

Mathematics anxiety as constraint of math achievement

During recent years, anxiety about the prospect of doing mathematics has been recognized as a significant factor shaping math learning, math performance, and basic numerical abilities of adults in the classroom (Maloney & Beilock, 2012), workplace (Bursal & Paznokas, 2006; McMullan, Jones, & Lea, 2010; Pozehl, 1996; Swars, Daane, & Giesen, 2006), and consumer decisions they make (Jones, Childers, & Jiang, 2012; Suri, Monroe, & Koc, 2013). Math anxiety has been found to be negatively related to math achievement both because it leads to avoidance of math and because it disrupts the working memory resources students use to solve difficult math problems in the moment (Ashcraft, 2002; Ashcraft & Kirk, 2001; Hembree, 1990; Lyons & Beilock, 2012; Park, Ramirez, & Beilock, 2014). Working memory (WM) is an important cognitive construct involved in maintaining relevant information in a highly active state and inhibiting interfering information (Engle, 2002). Unfortunately, math anxiety can cause negative thoughts and ruminations that co-opt the WM resources that individuals rely on to maintain superior performance in math. Evidence consistent with this hypothesis comes from behavioral studies (Ashcraft & Kirk, 2001; Park et al., 2014) and studies using brain imaging. For instance, functional magnetic resonance imaging (fMRI) studies have found that math anxiety is associated with reduced activity in WM-related brain regions (dorsolateral prefrontal cortex: Young, Wu, & Menon, 2012) as well as hyperactivity in brain regions associated with the processing of negative emotions and pain (right amygdala: Young et al., 2012; bilateral dorsal posterior insula: Lyons & Beilock, 2012).

Even though much the literature on math anxiety has focused mainly on adults, there is evidence that the detrimental effects of math anxiety start early. Recent work suggests that some children report experiencing math anxiety as early as first and second grades. Paradoxically, those with higher WM show the most pronounced negative relation between math anxiety and math achievement (Organization for Economic Cooperation & Development, 2013; Ramirez, Gunderson, Levine, & Beilock, 2013; Vukovic, Kieffer, Bailey, & Harari, 2013). The current work explores *why* math anxiety relates to poor math performance at the start of elementary school and *why* children with higher WM are particularly vulnerable to the deleterious effects of math anxiety. We argue that the math anxiety–achievement relationship might be mediated by less frequent use of the developmentally advanced problem solving strategies (described below) that predict superior math performance in young children.

Math problem solving strategies

Most children initially rely on rudimentary problem solving strategies such as finger counting to solve basic arithmetic problems at the beginning of formal schooling. With repeated use of rudimentary problem solving procedures, children develop strong problem–answer associations (e.g., they associate the answer 4 with the problem 2 + 2) that enable them to transition to more advanced problem solving strategies such as decomposition and retrieval, which rely heavily on memory-based processes (Laski et al., 2013; Siegler & Shrager, 1984). Retrieval involves directly recalling the solution to a problem from memory (e.g., 6 + 6 is 12). Decomposition, arguably the most WM-intensive arithmetic problem solving strategy, requires the use of multiple steps that involve breaking down the numbers in the problem into smaller sets and reconstructing the problem. For instance, to solve 6 + 6, a child who uses a decomposition strategy might break it down to (5 + 1) + (5 + 1) or 5 + 5 + 2, retrieving the answer to 5 + 5, and then adding 2 via retrieval or counting.

Although children use a mixture of strategies to solve math problems of various difficulty levels throughout development (Ashcraft, 1982; Carr & Alexeev, 2011; Fennema, Carpenter, Jacobs, Franke, & Levi, 1998; Siegler & Jenkins, 1989; Siegler & Shrager, 1984), the use of advanced memory-based strategies is important across all stages in schooling (Davis & Carr, 2002; Fuson, 1992; Woodward et al., 2012). Advanced memory-based strategies provide foundation for more complex math and are associated with higher conceptual understanding and achievement in math (Barrouillet & Lépine, 2005; Geary, 1990, 1993, 2011; Mazzocco, Devlin, & McKenney, 2008). Hence, in the United States, there has been widespread interest among policymakers and educators in helping children to transition to using advanced memory-based strategies (National Council of Teachers of Mathematics, 2000; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010) with the majority of this work focused on helping teachers and parents to expose children to diverse math problem solving strategies (Carr, Jessup, & Fuller, 1999; Ginsburg, 1997; Moely et al., 1986; Rittle-Johnson & Star, 2007; Rittle-Johnson, Star, & Durkin, 2009).

This focus on teaching a broad range of problem solving strategies is of course important; however, there are cognitive as well as affective constraints that could interfere with the use and more general adoption of advanced memory-based strategies. Even though advanced memory-based strategies (e.g., decomposition, retrieval) may seem effortless after extended practice, these strategies initially place high demands on WM, requiring children to retrieve facts directly from long-term memory, inhibit competing answer choices, and maintain intermediate steps (DeStefano & LeFevre, 2004; Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Kaye, deWinstanley, Chen, & Bonnefil, 1989; Zbrodoff & Logan, 1986). Neuroimaging work supports a link between WM and the use of advanced memory-based strategies by demonstrating that the use of these strategies is associated with greater activation in brain regions involved in effortful control in young children (left ventrolateral prefrontal cortex: Cho, Ryali, Geary, & Menon, 2011).

To the extent that advanced strategies are—at least initially—WM demanding, it follows that individual differences in children's WM may predict the use of advanced strategies because these strategies load heavily on WM. Indeed, children with higher WM do generally show a greater deployment of advanced strategies and overall higher math achievement than their lower WM peers (Barrouillet & Lépine, 2005; Cokely, Kelley, & Gilchrist, 2006; DeCaro, Thomas, & Beilock, 2008; Geary, 1990, 1993; Rosen & Engle, 1997). The differential use of strategies across children with higher versus lower WM might at least partially explain why children with higher WM seem to be vulnerable to the deleterious effects of math anxiety on math achievement.

We reasoned that if anxiety-related worries co-opt the WM resources that individuals rely on to support advanced memory-based strategies (Ashcraft & Kirk, 2001; Beilock, Kulp, Holt, & Carr, 2004; DeStefano & LeFevre, 2004; Imbo & Vandierendonck, 2007; Park et al., 2014; Schmader & Johns, 2003), then children with higher WM may find it difficult to deploy the advanced memory-based strategies they otherwise would use. Higher math anxiety may reduce the efficiency and, hence, use of effortful strategies that help high-WM children to perform at a high level in math. By contrast, children lower in WM might be less susceptible to the math anxiety-induced disruptions to WM because they typically rely on rudimentary strategies (e.g., counting) that are less demanding of WM resources and also associated with lower math achievement (Barrouillet & Lépine, 2005; Geary, 1990, 1993). Work with adults supports this reasoning. Specifically, lower WM adults tend to use rudimentary problem solving strategies regardless of their affective state, which has been used to explain why they typically do not show a strong relation between anxiety and performance (Beilock & DeCaro, 2007; Gimmig, Huguet, Caverni, & Cury, 2006). However, to our knowledge, the relation among individual differences in math anxiety, WM, and math problem solving strategy use has not been examined in young children.

In the current work, we examined the relation between math anxiety and strategy use in early elementary school students because this is the period during which many children transition from using rudimentary strategies such as counting to using advanced memory-based strategies such as retrieval and decomposition when solving arithmetic problems (Ashcraft & Fierman, 1982; Geary, Widaman, Little, & Cormier, 1987). If the math anxiety–achievement relationship is mediated by less frequent use of the developmentally advanced problem solving strategies that predict superior math performance in young children, then such a finding opens a new approach into remediating the negative effects of math anxiety on math performance at a young age. Specifically, techniques that help children to use optimal strategies—regardless of math anxiety—may help to sever the math anxiety–achievement link.

Of course, we recognize that there are many contextual factors that can affect children's math achievement and strategy use, including the quality of math instruction (Jordan & Levine, 2009) and access to favorable resources that relate to academic achievement (Bryk & Raudenbush, 1988; Starkey & Klein, 2006). To better control for these contextual factors, we used percentage of students who qualify for free or reduced lunch as a proxy for school-level socioeconomic status (SES). Using percentage of students who qualify for free or reduced lunch allowed us to better investigate how children's math anxiety and WM (above and beyond their learning context) may relate to children's use of math problem solving strategies.

Method

Participants

The data for this study were collected as part of a larger study examining children's achievement and attitudes about math (Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015). The sample consisted of 256 children in the first grade (139 girls) and 308 children in the second grade (167 girls). The sample of 564 children includes those who attended a traditional elementary school (i.e., not a gifted school), who are native English speakers, and who were not identified as requiring special education services by their teacher. The sample excludes children who were unwilling to follow the task instructions during the sessions or refused to cooperate, as identified by an experimenter at the time of testing ($n = 19$). We needed to exclude an additional set of children due to experiment error in administering the Woodcock–Johnson Applied Problems subtest, which resulted in not reaching the basal or ceiling criteria ($n = 51$), and due to experiment error in recording child responses on the strategy report problem set ($n = 29$).

The measures were obtained during the fall of the school year, and the average age of participating children whose parents reported this information was 7.13 years ($SD = 0.63$, range = 5.30–9.89). The average age for first graders was 6.64 years ($SD = 0.44$), whereas the average age for second graders was 8.84 years ($SD = 0.46$). We also obtained school records of the percentage of children who qualify for free or reduced lunch (our measure of SES). Within our sample of 564 children, we found that the top third of the sample, in terms of income, came from schools with 0 to 33.3% free or reduced lunch, the middle third came from schools with 41.9 to 82.8% free or reduced lunch, and the bottom third came from schools with 83.7 to 94.0% free or reduced lunch.

Tasks

To explore the relation among strategy use, math anxiety, and math achievement, we focused on the following tasks.

Math anxiety

The revised Child Math Anxiety Questionnaire (CMAQ-R) was a modification of a previously used Child Math Anxiety Questionnaire (C-MAQ: Ramirez et al., 2013; Mathematics Anxiety Rating Scale for Elementary School Students [MARS-E]: Suinn, Taylor, & Edwards, 1988). The CMAQ-R was designed to be appropriate for first and second grade children and involves 16 items that ask children how nervous they would feel during various math-related situations. The revision of the original CMAQ allowed us to assess children's anxiety for a broader range of math problems (i.e., math problems with strong spatial processing requirements such as graphs) that were not well represented in the original CMAQ. In addition, whereas the original CMAQ (Ramirez et al., 2013) required children to respond by pointing to a sliding scale anchored by a calm face and an anxious face, the revised CMAQ required children to respond by pointing to one of five smiley faces displaying an emotional gradient from *not nervous at all* (1) to *very, very nervous* (5) in a left to right format consistent with children's emotional magnitude estimations (Holmes & Lourenco, 2011).

Some items within the CMAQ-R directly address children's feelings of nervousness while solving particular math problems (e.g., "There are 13 ducks in the water, and there are 6 ducks on land. How many ducks are there in all?"), whereas other items present children with more general situations that involve doing mathematics in the classroom (e.g., "being called on by a teacher to explain a math problem on the board"). All children were provided with a simple explanation about what it means to be nervous and were instructed to point to one of five faces (from *not nervous at all* to *very, very nervous*) to indicate how various situations would make them feel. Children also were given a few example questions that did not involve math activities and were provided with feedback about how to respond using the face scale (e.g., "How nervous would you feel looking down from a really tall building?").

Working memory

Children were administered the forward and backward letter span tasks, which were adapted from the forward and backward digit span tasks on the Wechsler Intelligence Scale for Children—Third Edition (Wechsler, 1991). A composite of these tasks (number of correct trials across forward and backward tasks) served as our WM measure. The forward and backward letter span scores were combined because WM is thought to be composed of memory processes measured by forward span as well as by executive function processes measured by backward span (Baddeley, 2000). In the forward span task, the experimenter read a sequence of letters at a rate of one letter per second and asked children to recall them in a forward order (e.g., "F, Q, L"). The backward span task was similar except that children were asked to recall the letter sequence in a backward order (e.g., "B, H, M" = "M, H, B"). The forward span set size ranged from 2 to 9 items, whereas the backward span set size ranged from 2 to 8 items. Each set size was assessed on two trials, and children began with the smallest set size of 2. Children who completed one or both trials at a particular set size correctly were given two additional trials at the next set size. The digit span task ended when children were incorrect on both trials of a given set size. The letters used for forward and backward letter span tasks were B, F, H, J, L, M, P, Q, and R. No letter was repeated within a given set. The forward letter span task was always administered before the backward letter span task. For the backward letter span task, children received a practice trial before starting the assessment trials.

Math achievement

The Applied Problems subtest from the Woodcock–Johnson III (WJ-III; Woodcock, McGrew, & Mather, 2001) was used to assess children's math achievement. This task includes math word problems of increasing difficulty that require comprehension of the nature of the problem, identification of relevant information, and performance of relevant calculations. The contents of the problems included single digit to more complex arithmetic, fractions, and basic geometry. We used the Applied Problems *W*-score, a transformation of the raw score into a Rasch-scaled score with equal intervals, to derive a measure of math achievement for each child. For this measure, a score of 500 is approximately the average performance of a 10-year-old.

Strategy report problem set

After completing the Applied Problems subtest, children completed a short set of math problems that were used to assess their math problem solving strategies. The strategy report problem set consisted of four addition word problems that were presented in order of increasing difficulty. We used the following problems (in word problem form), which were designed to be grade appropriate and in line with the type of problems children encountered in the Woodcock–Johnson Applied Problems subtest: 3 + 6, 9 + 8, 13 + 5, and 14 + 19. Children were not given paper and pencil to solve the problems. Before the first problem was presented, children were told that they would be presented with a few math problems and that they should try to solve the problems any way they wanted. Children were further instructed to say each answer aloud as soon as they arrived at it and to report how they solved each problem.

While administering the task, each problem was placed in front of children and the experimenter read it aloud (e.g., "If you had nine crayons and someone gave you eight more, how many would you have altogether?"). The word problems had no visual aids (e.g., no pictures of crayons). Trained experimenters recorded any overt strategies children spontaneously used such as finger counting, pointing, and counting aloud for each problem. After children provided an answer, the experimenter recorded the amount of time it took to solve the problem using a stopwatch and then asked, "So how did you solve the problem?" to get more detailed information about children's problem solving strategies. Observing spontaneous strategies and probing strategy use have been shown to be internally consistent, providing a valid way to capture children's problem solving strategies (Carr & Jessup, 1997; LeFevre, Smith-Chant, Hiscock, Daley, & Morris, 2003; Siegler, 1989).

In previous studies, researchers have classified children's strategies immediately after the children provided self-reports of how they solved the problems (Geary, 1990; Siegler, 1987). In the current study, however, trained experimenters took detailed notes about visible signs of strategies they noticed to allow two independent raters who were more familiar with strategy coding to classify strategies at a later time. The two independent raters began classifying the strategies by coding children's verbal reports without reference to accuracy or experimenter reports of children's overt behavior. The raters assigned the strategies to one of the following categories: counting (child described using a counting procedure such as counting fingers), decomposition (child described breaking down the presented addends into simpler numbers), retrieval (child described spontaneously knowing the answer, stated the answer in a matter-of-fact fashion, or simply repeated the problem and answer), guessing (child reported that he or she did not attempt to solve problem and/or explicitly said he or she guessed), or unknown (child did not provide an answer, provided an ambiguous procedure, or said he or she used multiple conflicting approaches). We were unable to use the amount of time children took on each problem to inform our strategy coding due to inconsistent time measurement procedures used by the experimenters.

Procedure

All tasks were completed in a school setting and were administered one-on-one to each child. The measures of achievement (WJ-III Applied Problems, strategy report problem set, and letter span) and math anxiety (CMAQ-R) were assessed on 2 separate school days, with the achievement session being completed first. On average, children completed the emotion session approximately 4 days after the achievement session (mean difference = 4.01, $SD = 0.015$).

The achievement session took an average of 30 min. The tasks in this session were described to children as "fun letter and number games." The math anxiety questionnaire (CMAQ-R), administered as part of a larger battery of emotion measures, took 5 to 7 min during the second session, which took approximately 25 min in total and included other attitude measures about math. The CMAQ-R was introduced to children as a question game in which the experimenter would ask children a series of questions about the kinds of things that made them feel nervous.

Results

Strategy coding and data pre-processing

Two independent coders showed a simple agreement of 90% after the initial pass (kappa of .91, $p < .001$). For all of the trials where the coders did not initially agree (as well as those where they indicated that the strategy was unknown), the two independent raters clarified the final assigned code through either an examination of visible counting references that were initially noted by research assistants (.05% of trials), a discussion between coders (~4% of trials), or relying on the child's history on the other problems that the child was presented with (5% of trials). All of the remaining unknown trials that could not be clarified were left as unknown. Trials that were initially classified as retrieval because the child simply repeated the problem and answer (e.g., "because 3 + 6 is 9") but showed evidence of overt counting were reclassified as counting (<1% of retrieval trials). The remaining retrieval trials where the child repeated the problem and answer (e.g., "because 3 + 6 is 9) remained classified as retrieval. Hence, all of the trials classified as retrieval were ones where children provided a retrieval strategy in their self-report and showed no evidence of counting. Admittedly, this coding approach does not rule out other strategies that children may have rapidly deployed internally, but it does provide us with an index of the strategies children likely relied on when solving problems.

We used a trimming procedure to remove outliers at the trial level on the basis of the answers provided because some children gave extreme responses to the problems (<1% of trials). This trimming procedure involved (a) removing trials where children reported extreme answers that were beyond any reasonable addition calculation (i.e., answers that were >100) and (b) removing remaining trials where children's response deviations were 4 standard deviations or more from the correct answer for each particular problem. We applied this trimming procedure within each strategy category.

Given the ambiguity in the literature about what differentiates retrieval attempts from guessing, we differentiated retrieval trials into *strong* retrieval (retrieval trials where the answer given was within 1 unit of the correct answer) and *weak* retrieval (retrieval trials where the answer was >1 unit from the correct answer). Classifying strategies based on solutions provided is a procedure that has been used in previous studies assessing young children's math problem solving strategies (McNeil, 2007; Perry, Breckinridge Church, & Goldin-Meadow, 1988). Classifying retrieval in this manner allowed us to make an important distinction about the different ways in which children rely on memory-based processes to solve arithmetic problems and how these processes align with or differ from guessing. Using the aforementioned strategy categories, we created an advanced memory strategy variable by combining decomposition trials with strong retrieval trials, which served as one of our primary outcome variables.

Math achievement

Children's average *W*-score on the Woodcock–Johnson measure was 462.84 (SD = 20.58), and their average grade equivalent score was 2.23 (SD = 1.15). Not surprisingly, second graders (M = 470.69, SD = 19.73) showed a higher average *W*-score than first graders (M = 453.40, SD = 17.40), $t = -10.93$, $p < .01$. Children's mean correct performance on the four problems that made up the strategy report task was 1.88 (SD = 1.38), with second graders (M = 2.47, SD = 1.20) once again outperforming first graders (M = 1.19, SD = 1.27), $p < .01$. Problem solving accuracy on the strategy report task was strongly related to accuracy on the WJ-III Applied Problems subtest (r = .755, $p < .01$), which supports our use of the strategy report task as a proxy for how children might be solving problems on the WJ-III Applied Problems subtest.

Math anxiety

Children's math anxiety was calculated by taking an average response over all of the items on the CMAQ-R. The mean CMAQ-R was 2.41 (SD = 0.74). Approximately 26% of children self-reported experiencing medium to high levels of math anxiety (average response of 3 and above). These results provide evidence that even in early elementary school there exists variability in children's self-reported feelings of nervousness about situations involving math, with a significant proportion of children already falling prey to medium to high levels of math anxiety. We found that our 16-item math anxiety questionnaire showed strong reliability (alpha = .83; Maloney et al., 2015).

Working memory

WM scores were calculated by taking the sum of the forward and backward letter span tasks. Children in our sample showed a mean forward span score of 5.49 (SD = 1.73) and a mean backward span score of 2.71 (SD = 1.32). When we combined these two measures, the mean total span was 8.20 (SD = 2.51) overall, with second graders showing a higher total span (M = 8.62, SD = 2.50) than first graders (M = 7.70, SD = 2.46), $t = -4.37$, $p < .01$).

Overall frequency and accuracy of strategies used

We first examined how frequently children used each strategy during the strategy report task by calculating the mean percentage of use for each strategy category at the trial level. The counting strategy, on average, was used more frequently than any other problem solving strategy (M = 52%, SD = 50), followed by decomposition (M = 12%, SD = 31), strong retrieval (M = 8%, SD = 27), guessing (M = 8%, SD = 27), and finally weak retrieval (7%, SD = 25). Approximately 12% (SD = 33) of trials were classified as unknown. Although the percentage of trials coded as unknown reduces our ability to characterize children's strategies, this approach respects the reliability of children's self-reports and limits errors in the coding of self-report of strategies that present insufficient information or too many conflicting cues (LeFevre et al., 2003; Threlfall, 2009).

There was a significant difference in strategy use across the five categories of interest (counting, decomposition, strong retrieval, weak retrieval, and guessing), Friedman test, $\chi^2(4) = 2002.25$, $p < .01$. A set of pairwise comparisons revealed that all of the categories of interest were used at significantly different rates ($p < .02$) except for guessing, weak retrieval, and strong retrieval, which were used at rates that did not significantly differ from each other ($p > .05$). Table 1 displays the frequency of strategy use broken down by grade.

Children's mean correct performance on the four problems that made up the strategy report task was 1.88 (SD = 1.38). In terms of problem accuracy, we found that overall children solved 47% (SD = 50) of the problems correctly and that the use of decomposition and strong retrieval was associated with the highest accuracy (M = 76%, SD = 43 and M = 82%, SD = 39, respectively). Counting showed the next highest accuracy (M = 57%, SD = 50), followed by unknown (M = 17%, SD = 38), guessing (M = 5%, SD = 21), and finally weak retrieval, which by definition did not capture any correct responses. A set of independent samples t-tests showed that the mean accuracy of the different strategy categories were all significantly different from one another (all $ps < .05$) with the exception of decomposition and strong retrieval, which were solved at a comparable rate of accuracy ($p > .05$). A breakdown of accuracy by grade level is displayed in Table 1. These results demonstrate that early elementary school is characterized by considerable variation in children's strategy use. We next asked how children's use of strategies related to their math anxiety and WM.

Table 1
Frequency and accuracy of problem solving strategies by grade level.

	Frequency [mean (*SD*)]	Accuracy [mean (*SD*)]
First grade		
Counting	.49 (.50)	.44 (.50)
Decomposition	.05 (.22)	.60 (.49)
Strong retrieval	.04 (.31)	.62 (.49)
Weak retrieval	.11 (.31)	.00 (.00)
Guessing	.12 (.32)	.06 (.26)
Unknown	.18 (.38)	.11 (.31)
Second grade		
Counting	.55 (.50)	.66 (.47)
Decomposition	.17 (.38)	.80 (.40)
Strong retrieval	.11 (.31)	.88 (.33)
Weak retrieval	.04 (.19)	.00 (.00)
Guessing	.05 (.21)	.02 (.13)
Unknown	.08 (.27)	.29 (.46)

Relation among math anxiety, strategy reports, and math achievement for children who were higher and lower in WM

For the regression, correlation, and mediation analysis presented below, we removed outliers that were 2.5 standard deviations from the mean for our measures of interest (5% of the data) and six model residual outliers. Data for these participants were excluded from further analysis. We began by first establishing that there is a simple bivariate correlation between children's math anxiety and math achievement ($r = -.281$, $p < .01$). Children's self-reported math anxiety was negatively associated with their math achievement, with the strength of this correlation in line with past research (Hembree, 1990). We next asked whether the math anxiety–achievement relation would hold among groups of students who were higher and lower in WM. To address this, we regressed WM and math anxiety (both as continuous variables), as well as the WM × Math Anxiety interaction, on children's math achievement (*W*-score). This model also included the school level percentage of students who qualify for free or reduced lunch as a covariate to account for the SES variability within our sample. All of the predictors (except for the interaction term) in the regression model were standardized.

Before running our regression model, we found that there were 45 participants who had missing data for at least one of our model variables. These participants would be completely ignored under a list wise deletion procedure. Hence, to better account for the loss of power, we verified that the missing cases were missing completely at random (MCAR; $\chi^2 = 4.40$, $p > .05$) and then ran our main regression model using a pairwise deletion procedure that excludes the specific missing values (not the entire case) from the analysis. The results of our main regression analysis showed a significant coefficient of SES ($\beta = -3.75$, $t = -4.90$, $p < .01$), WM ($\beta = 7.76$, $t = 9.88$, $p < .01$), and math anxiety ($\beta = -3.457$, $t = -4.65$, $p < .01$) as well as the critical Math Anxiety × WM interaction ($\beta = -1.73$, $t = -2.28$, $p = .023$). Fig. 1 plots the regression interaction using grade equivalent scores for the Woodcock–Johnson III Applied Problems subtest as the dependent variable for ease of interpretation. A significant Math Anxiety × WM interaction was also obtained when we ran the regression model without SES as a covariate ($\beta = -1.53$, $t = -1.97$, $p < .05$).

In line with previous findings, children with higher WM showed a pronounced negative relationship between math anxiety and math achievement (Ramirez et al., 2013; Vukovic et al., 2013). However, considering the variation in children's WM across grade, one might wonder whether our effects are driven by grade level differences in WM. To address this issue, we performed an additional regression in which we standardized total digit span for first and second graders independently (effectively creating a proxy for children's WM capacity relative to their same-grade peers). Once again, we found a significant Math Anxiety × WM interaction term ($\beta = -1.81$, $t = -2.34$, $p = .020$), indicating that the

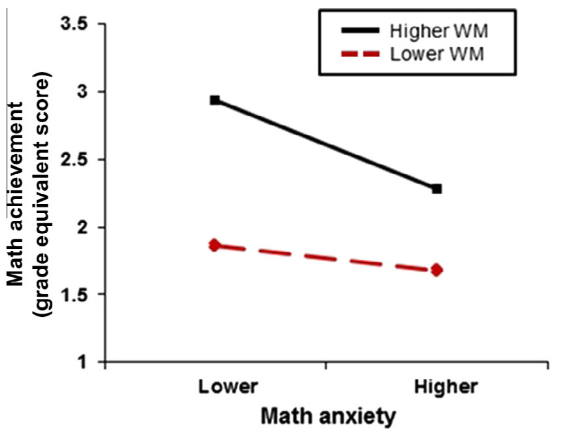

Fig. 1. Students' math achievement (grade equivalent scores) as a function of individual differences in working memory and math anxiety. Working memory and math anxiety are plotted at 1 standard deviation above and below the mean.

math anxiety–achievement relation is most pronounced for both first and second graders who are higher in WM within their respective grades and is less pronounced for both first and second graders who are lower in WM within their respective grades.

To further explore the main Math Anxiety × WM interaction and its relation to strategy use, we divided children based on working memory (median split) into higher and lower WM groups. Children with a total letter span score between 2 and 7 were defined as lower WM ($n = 221$), and children with a total digit span score between 8 and 14 were defined as higher WM ($n = 304$). Between-group comparisons showed that children with higher WM showed higher math achievement on the WJ-III Applied Problems subtest ($t = -11.47$, $p < .001$) and better performance on the strategy report task ($t = -9.29$, $p < .001$) than children with lower WM (see Table 2).

In terms of strategy use, we found that children with higher WM showed greater use of decomposition ($t = -5.79$, $p < .001$) and strong retrieval ($t = -2.41$, $p < .05$) relative to children with lower WM. As we might expect, children with higher WM also showed greater use of advanced memory-based strategies (decomposition and strong retrieval combined, $t = -5.99$, $p < .001$) than children with lower WM. By contrast, children with lower WM showed greater use of weak retrieval ($t = 4.48$, $p < .001$) and guessing ($t = 5.07$, $p < .001$) relative to children with higher WM. The use of counting and unknown strategies did not significantly differ for children with higher and lower WM (both $ps > .05$).

We next examined the relation of math anxiety to math achievement and strategy use in children with lower and higher WM (see Table 3). For children with lower WM, we found that math anxiety did not significantly relate to math achievement or to any of the strategy categories ($p > .05$) with the exception of the guessing strategy ($r = .17$, $p < .05$) such that children who were higher in anxiety reported more guessing. All of the strategy categories were significant predictors of lower WM children's math achievement, with counting, advanced memory, decomposition, and strong retrieval serving as positive predictors (all $ps < .05$) and weak retrieval, guessing, and unknown serving as negative predictors (all $ps < .05$).

In contrast to the lower WM children, the results for children with higher WM showed that math anxiety was a significant negative predictor of children's math achievement overall ($r = -.36$, $p < .01$) as well as when we examined higher WM first graders ($r = -.254$, $p < .01$) and higher WM second graders ($r = -.294$, $p < .01$) separately. In addition, among children high in WM, math anxiety was negatively related to the use of advanced memory-based strategies—retrieval and decomposition combined ($r = -.23$, $p < .01$) as well as decomposition alone ($r = -.21$, $p < .01$)—and positively related to the use of weak retrieval ($r = .14$, $p < .05$) as well as strategies categorized as unknown ($r = .19$, $p < .01$). Furthermore, all of the strategy categories (except for counting) were significant predictors of children's math achievement, with advanced memory, decomposition and strong retrieval serving as positive predictors ($ps < .001$) and weak retrieval, guessing, and unknown serving as negative predictors (all $ps < .001$).

Table 2
Descriptive statistics for math achievement, strategy report task, math anxiety, and frequency of strategy use by WM group.

	Lower WM [mean (*SD*)]		Higher WM [mean (*SD*)]	
Math achievement (*W*-score)	452.77	(16.24)	470.39	(18.15)***
Strategy report	1.29	(1.32)	2.33	(1.23)***
Math anxiety	2.56	(0.75)	2.30	(0.71)***
Strategy report categories				
Counting (% use)	53	(37)	54	(35)
Decomposition (% use)	5	(12)	16	(26)***
Strong retrieval (% use)	6	(15)	09	(19)*
Advanced memory (% use)	11	(21)	26	(32)***
Weak retrieval (% use)	10	(20)	4	(11)***
Guessing (% use)	13	(25)	4	(14)***
Unknown (% use)	12	(21)	12	(20)

* $p < .05$.
*** $p < .001$.

Table 3
Correlations among math anxiety, math achievement, and frequency of strategy use by WM group.

Lower WM	Measure							
	1	2	3	4	5	6	7	8
1. Math anxiety								
2. Math achievement (*W*-score)	−.05							
3. Counting (% use)	−.04	.35**						
4. Advanced memory (% use)	−.04	.33***	−.31***					
5. Decomposition (% use)	−.04	.35***	−.11	.70***				
6. Strong retrieval (% use)	−.02	.17*	−.33**	.81***	−.15*			
7. Weak retrieval (% use)	−.03	−.37**	−.39**	−.06	−.19**	.07		
8. Guessing (% use)	.17*	−.32**	−.53**	−.17*	−.13	−.13	−.07	
9. Unknown (% use)	−.09	−.15*	−.38***	−.164*	−.12	−.13	−.13	−.06
	Measure							
Higher WM	1	2	3	4	5	6	7	8
1. Math anxiety								
2. Math achievement (*W*-score)	−.36**							
3. Counting (% use)	.02	−.09						
4. Advanced memory (% use)	−.23***	.47***	.69***					
5. Decomposition (% use)	−.21**	.41***	−.51***	.80***				
6. Strong retrieval (% use)	−.1	.26***	−.46***	.58***	−.03			
7. Weak retrieval (% use)	.14*	−.28***	−.24***	−.11*	−.18**	.06		
8. Guessing (% use)	.09	−.24***	−.24***	−.14*	−.14*	−.04	.10	
9. Unknown (% use)	.19**	−.28***	−.34***	−.21***	−.18**	−.11	−.03	−.09

* $p < .05$.
** $p < .01$.
*** $p < .001$.

The fact that higher math anxiety was negatively related to children's use of advanced memory-based strategies, which in turn negatively predicted children's math achievement, suggests that for higher WM children the use of advanced memory-based strategies might mediate the math anxiety–achievement relation.

Mediation analysis

We next tested the hypothesis that the *frequency of advanced memory strategy use* would account for the math anxiety–achievement relation among children who were higher in WM. We carried out the mediation analysis by focusing on the subsample of children with higher WM (based on the median split we previously defined) because this group of children demonstrated a more pronounced Math Anxiety × Achievement interaction. Within this sample of higher WM children, we looked only at children who completed all four problems during the strategy report problem set ($n = 266$). We tested our mediation hypothesis using a widely used causal steps approach (Baron & Kenny, 1986) that tests the effects of each individual path (a, b, and c′; see Fig. 2) to assess the effects of the mediator in the model. As in our main analysis, school level SES served as a covariate. Mediation analysis, using Baron and Kenny's (1986) causal steps approach, revealed that there was a significant negative effect of math anxiety on math achievement ($c = -6.78$, $SE = 1.03$, $t = -6.59$, $p < .01$). Math anxiety was also negatively associated with frequency of advanced strategy use—decomposition and strong retrieval ($a = -0.07$, $SE = .02$, $t = -3.33$, $p < .01$)—and advanced strategy use predicted math achievement when controlling for the effect of math anxiety on math achievement ($b = 20.65$, $SE = 2.91$, $t = 7.09$, $p < .01$). In this mediation model, children's advanced strategy use had a partial mediation effect on the relation between math anxiety and math achievement, as indicated by the reduced magnitude of the direct effect of math anxiety on math achievement when the effect of the advanced strategy use was controlled ($c' = -5.36$, $SE = 0.96$, $t = -5.59$, $p < .01$) (see Fig. 2).

We also employed a bias-corrected bootstrapping method (Preacher & Hayes, 2004) that uses 1000 samples to assess the indirect effects of the predicted mediator in a mediator model between math

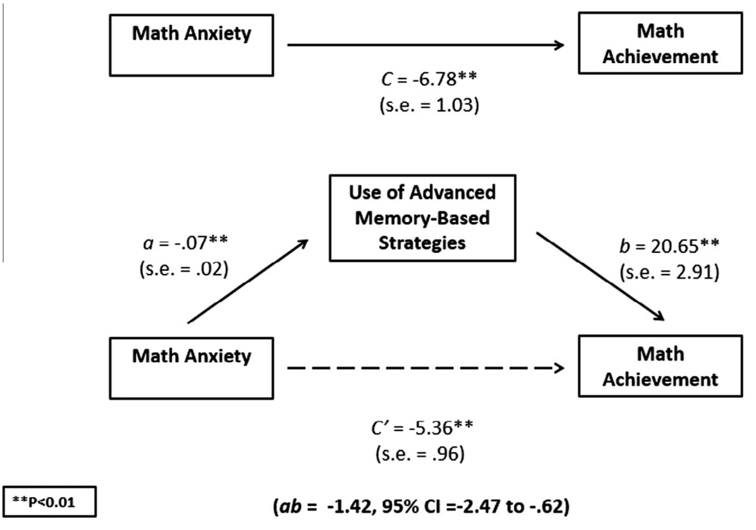

Fig. 2. Mediation analysis. Values represent unstandardized coefficients with standard errors in parenthesis. The use of advanced memory-based strategies partially mediates the relationship between math anxiety and math achievement.

anxiety and math achievement. As in our main analysis, school level SES served as a covariate. Using bootstrapping procedures, we found a significant indirect effect of advanced memory strategy use on the effect of math anxiety on math achievement (*ab* = −1.42, 95% confidence interval [CI] = −2.47 to −0.62). Table 4 presents the mediation results when we used the other strategy categories. One may wonder whether the relationship between math anxiety and math achievement is bidirectional, with math achievement also predicting math anxiety, mediated by advanced strategy use; however, when we ran the model with math achievement as a predictor and math anxiety as the outcome variable, the mediation effect of advanced strategy use was no longer significant.

Another complementary way of addressing our main research question is to ask whether the math anxiety–achievement relationship is mediated by higher WM children's greater use of some of the weakest strategies—guessing and weak retrieval combined. We find that children's use of guessing and weak retrieval combined also served as a partial mediator of the math anxiety–achievement relation (*ab* = −0.87, 95% CI = −1.64 to −0.29).

Finally, we also ran a moderated mediation analysis using the PROCESS macro (Hayes, 2015) for the full sample of children (rather than focusing only on the higher WM sample). Our goal in running a moderated mediation analysis was to assess whether the indirect effect of math anxiety on math

Table 4
Bootstrapped point estimates and confidence intervals for the indirect effect of math anxiety on math achievement using various strategy report categories as mediators.

Mediating variable	Indirect effect	Bootstrapping 95% CIs	
	(*ab* path estimate)	Lower	Upper
Strategy report categories			
Counting (% use)	−0.09	−0.50	0.12
Decomposition (% use)	−1.19	−2.10	−0.49
Strong retrieval (% use)	0.19	−0.76	0.26
Advanced memory (% use)	−1.42	−2.47	−0.62
Weak retrieval (% use)	−0.63	−1.43	−0.13
Guessing (% use)	−0.36	−0.94	0.04
Unknown (% use)	−0.27	−0.74	0

achievement through advanced strategy use is significantly more pronounced at higher levels of WM. We found that the index of moderated mediation was significant ($\beta = -1.42$, $SE = 0.43$, CI = -2.35 to -0.61), which provides further evidence of the important role of advanced strategies in the math anxiety–achievement relation of higher WM children.

In sum, across a variety of mediation methods, we found that the frequency of children's advanced strategy use significantly accounted for the negative relation between math anxiety and math achievement among children with higher WM. Higher levels of math anxiety were negatively related to the use of advanced strategies, which in turn predicted lower math achievement. One question that remains unanswered is how higher WM children perform when they persist in their use of advanced memory-based strategies despite their higher level of math anxiety. Math anxious children who use advanced memory-based strategies might execute these strategies inefficiently, which could lead to worse performance relative to children who reduce their use of these computationally demanding strategies. To address this, we examined the relation between advanced memory-based strategy use and math achievement for children who are higher in WM and higher in math anxiety (using a median split). We found that children who, despite their math anxiety, use more advanced memory-based strategies ($r = .433$, $p < .01$)—decomposition ($r = .369$, $p < .01$) and strong retrieval ($r = .212$, $p < .05$)—show higher math achievement. Thus, children whose WM is compromised by math anxiety may underperform because they tend to give up on the use of advanced memory-based strategies that help to support their success.

Discussion

Early math achievement is foundational for children's future success inside the classroom (Geary, 2013) and in the workplace (Rivera-Batiz, 1992). The benefits of knowing and using a variety of math problem solving strategies has been well documented in the early mathematics literature (Alibali & DiRusso, 1999; Carpenter, Franke, Jacobs, Fennema, & Empson, 1998; Resnick & Ford, 1981; Rittle-Johnson & Star, 2007; Star & Rittle-Johnson, 2009; Star & Seifert, 2006). Much of this work has concentrated on making key reform recommendations to expose students to a variety of math problem solving strategies (Hiebert & Carpenter, 1992; National Council of Teachers of Mathematics., 2000). And although there has been previous interest in understanding the cognitive and classroom factors that lead to the development of advanced strategies (Ashcraft & Stazyk, 1981; Geary, 2011; Laski et al., 2013; Siegler & Shrager, 1984), much of this work has ignored the role of children's own affect. Children's capability for improving their math skills is contingent on children feeling comfortable with mathematics in general as well as using the novel and cognitive demanding strategies they are taught. We investigated whether a higher degree of math anxiety relates to children's use of the advanced strategies they are taught. Supporting this hypothesis, we found that math anxiety is a negative predictor of the use of advanced problem solving strategies. Math anxiety may serve as an impediment to children's math performance by reducing their use of advanced problem solving strategies that are critical for math achievement.

Critically, however, not all children show a negative relation between math anxiety and the use of advanced memory-based strategies. We found that math anxiety negatively relates to advanced strategy use primarily for children with higher WM. We argue that children with higher WM have the most to lose because anxiety disrupts their use of advanced problem solving strategies that they could otherwise use to reach a superior level of performance in math. Our results support this interpretation by demonstrating that children's use of advanced memory-based strategies served as a partial mediator of the math anxiety–achievement relationship among children with higher WM.

Why are higher levels of math anxiety associated with reduced use of advanced strategies among higher WM children? One possibility is that children with higher WM attempt to use advanced strategies initially, but higher math anxiety interferes with their ability to fluently use these strategies. As a result, these higher WM, high math anxiety children reduce their reliance on advanced memory-based strategies. By contrast, children with lower WM may show fewer differences in their use of advanced strategies (and overall math performance) at varying levels of math anxiety because they tend to rely more on rudimentary problem solving strategies in the first place.

A somewhat different (but complementary) account is that math anxiety may also affect children's strategic behavior at a more fundamental level by discouraging children from choosing advanced strategies or even seeing advanced strategies as an option in the first place. Borrowing from Siegler and Shrager's (1984) strategy choice model, this alternative account suggests that math anxiety does not lead higher WM children to adaptively switch strategies but rather raises the confidence threshold that guides children's choice of which strategy to use to solve a particular math problem (Imbo & Vandierendonck, 2007; Wigfield & Meece, 1988). This lower use of advanced strategies can, over time, lead to lower levels of math achievement because advanced strategy use may itself propel conceptual understanding of numerical relations (Schneider, Rittle-Johnson, & Star, 2011). It is critical that we help children who are ready to use advanced strategies to feel comfortable in executing them during novel learning situations because early deployment of advanced strategies can play a particularly important role in subsequent performance (Seaman, Howard, & Howard, 2015). Whether math anxiety affects the efficacy of strategy execution or choice is up for debate. The fact remains that math anxiety is related to children's use (and perhaps knowledge) of advanced memory-based strategies, which in turn is negatively related to their math performance.

The results reported here bring up the interesting question of whether math anxious children who push forward in using WM-intensive strategies could fare worse than those who give up on trying to deploy these advanced memory strategies. After all, using effortful strategies when WM has been compromised might reduce problem solving efficiency and lead to more errors in the problem solving process (Ashcraft & Kirk, 2001; Eysenck & Derakshan, 2011). However, as reported in the Results section above, children's use of advanced memory-based strategies positively predicts math achievement even among children with higher WM and higher math anxiety. The fact that children do better when they push forward in using advanced memory-based strategies (despite their math anxiety) suggests that we need to ensure that math anxiety does not lead to reduced use of advanced strategies—particularly when children are first learning novel math (Seaman et al., 2015).

Our goal was to examine whether differential strategy use accounts for the anxiety–achievement relation among higher WM children. Although we found a relationship among math anxiety, strategy use, and achievement, the fact that the use of advanced strategies only partially mediates the anxiety–achievement relationship suggests that there are additional factors that prevent higher WM children from living up to their achievement potential. Math anxiety, for instance, may prevent children from learning mathematical concepts and applications in a more general manner. This interpretation is supported by Vukovic, Kieffer, and colleagues (2013), who found that math anxiety impairs the learning of mathematical applications longitudinally, but only for children with higher WM. Math anxiety may relate to math achievement in multiple ways—by disrupting WM, by interfering with the learning of basic math knowledge and strategies, by leading children to avoid math situations in general, and by contributing to and/or reinforcing poor numerical processing abilities (Maloney, Ansari, & Fugelsang, 2011; Maloney & Beilock, 2012; Maloney, Risko, Ansari, & Fugelsang, 2010).

Interventions for reducing math anxiety

With the high prevalence of math anxiety in our society, there has been growing attention to the question of how to reduce math anxiety among adults as well as children. One promising approach to treating math anxiety involves the use of an emotion regulation strategy termed *cognitive reappraisal*, which involves encouraging individuals to change their interpretation of affective stimuli (Gross, 1998). In adults, cognitive reappraisal has been found to be a long-lasting way to regulate affect (Davis & Levine, 2013; Kross & Ayduk, 2008; Ochsner & Gross, 2005; Ochsner, Silvers, & Buhle, 2012; Silvers, Buhle, & Ochsner, 2013; Silvers, Shu, Hubbard, Weber, & Ochsner, 2015). Moreover, recent work suggests that by 6 years of age, children use cognitive reappraisal spontaneously to attenuate affect (Davis, Levine, Quas, & Lench, 2010) and can also be directed to do so (Davis & Levine, 2013). Thus, investigating the benefits of using cognitive reappraisal in general as well as the principles of cognitive reappraisal (Mavilidi, Hoogerheide, & Paas, 2014) is a promising direction for future interventions designed to reduce math anxiety.

One important starting point for improving attitudes about mathematics and how children perform is to prevent children from developing math anxiety in the first place. Working with teachers

(Beilock, Gunderson, Ramirez, & Levine, 2010; Harper & Daane, 1998; Swars, Daane, & Giesen, 2006) as well as with parents (Berkowitz, Schaeffer, Levine, & Beilock, 2015; Maloney et al., 2015; Vukovic, Roberts, & Green Wright, 2013) to change the (negative) ways they interact with their children about math is likely important for stemming children's math anxiety and increasing positive attitudes about math (Maloney et al., 2015).

Conclusion

Math anxiety is a problem that can negatively affect children's academic achievement and future employment prospects. Here we found that for children who are higher in WM, greater math anxiety is negatively related to their use of advanced problem solving strategies, which could have implications for their long-term math achievement. A delay in developing a diverse repertoire of strategies may not only limit children's math performance but also affect their flexible mathematical thinking more generally and reduce their conceptual understanding of mathematics (Rittle-Johnson & Star, 2007; Rittle-Johnson et al., 2009). It is important for children to overcome their anxiety about math and to flexibly use a variety of problem solving strategies, including those that they might not feel completely comfortable in implementing (Ambady, Shih, Kim, & Pittinsky, 2001; Beilock et al., 2010). Enabling students to more effectively deploy the strategies that predict success in mathematics will require not only teaching students math content but also providing them with ways in which to alleviate the anxiety they experience when engaging in mathematical thinking.

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