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ARTICLE

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Although math anxiety is associated with poor mathematical knowledge and low course grades (Ashcraft & Krause, 2007), research establishing a connection between math anxiety and math achievement has generally been conducted with young adults, ignoring the emergence of math anxiety in young children. In the current study, we explored whether math anxiety relates to young children's math achievement. One hundred and fifty-four first- and second-grade children (69 boys, 85 girls) were given a measure of math achievement and working memory (WM). Several days later, children's math anxiety was assessed using a newly developed scale. Paralleling work with adults (Beilock, 2008), we found a negative relation between math anxiety and math achievement for children who were higher but not lower in WM. High-WM individuals tend to rely on WM-intensive solution strategies, and these strategies are likely disrupted when WM capacity is co-opted by math anxiety. We argue that early identification and treatment of math anxieties is important because these early anxieties may snowball and eventually lead students with the highest potential (i.e., those with higher WM) to avoid math courses and math-related career choices.

Math anxiety has long been recognized to play a role in the math achievement of middle school and high school students (Hembree, 1990). Various studies have linked math anxiety to increased worries about math failure (Richardson & Woolfolk, 1980), to an avoidance of math and/or numerical tasks (Krinzinger, Kaufmann, & Willmes, 2009), and to an increased cortisol response when performing math tasks (Faust, 1992; Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011). Even the prospect of doing math has been found to be enough to elicit a negative emotional response among students with high math anxiety (Lyons & Beilock, 2010). Math anxiety is worrisome because it negatively impacts mathematical knowledge, math grades, and standardized test scores in young adults (Ashcraft & Krause, 2007; Suinn, Taylor, & Edwards, 1988). Moreover,

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math anxiety is likely to impact the achievement of many students given that survey results show that the majority of individuals in the United States, regardless of cultural and economic background, dislike and fear mathematics (Burns, 1998; Zaslavsky, 1994) and report having negative experiences with math as early as elementary school (Jackson & Leffingwell, 1999).

Although math anxiety has been extensively studied, little is known about the emergence of math anxiety in young children. Indeed, most studies of math anxiety have focused on middle school or high school students, and the few published studies investigating math anxiety in elementary school have focused on children who are in fourth grade or beyond (Bush, 1991; Chiu & Henry, 1990; Suinn et al., 1988). For example, Suinn et al. (1998) asked 1,119 fourth, fifth, and sixth graders to complete a 26-item math anxiety questionnaire and found that students' level of math anxiety was negatively correlated with achievement scores on the Stanford Achievement Test of mathematics skills.

In the present study, we examine whether math anxiety is present even earlier in elementary school, in first- and second-grade students. To our knowledge, this is the first study to explore whether math anxiety is present at such a young age. We believe that it is important to address math anxiety at the earliest possible ages because early math anxiety may ''snowball'' in ways that lead to increased anxiety, dislike, and avoidance of math (Wigfield & Meece, 1988). Further, identifying math anxiety early is the first step in designing interventions to ameliorate these anxieties, which in turn may contribute to higher math achievement in the population.

In examining math anxiety in young children, we formulated our specific hypothesis based on the rich findings on math anxiety in older students. This literature has revealed that math anxiety may negatively impact math performance by co-opting the limited working memory (WM) resources that are crucial for successful math problem solving, which we refer to as ''WM disruption'' (Ashcraft & Kirk, 2001; Ashcraft & Moore, 2009; Engle, 2002; Young, Wu, & Menon, 2012).

In one study examining the impact of math anxiety on WM, Ashcraft and Kirk (2001) asked both low and high math-anxious college students to perform two-column addition problems requiring a carry operation, which placed a load on WM. Participants performed these problems in combination with a secondary letter memory task that involved the maintenance of either two-letter strings or six-letter strings in memory. When under the two-letter load, math error rates among participants who were higher in math anxiety were only slightly larger than those who were lower in math anxiety. However, when under the six-letter load, participants who were higher in math anxiety produced significantly more math errors than lower math-anxious individuals. The authors concluded that the high letter load was particularly detrimental to the participants who were higher in math anxiety because their worries about math co-opted WM resources that might otherwise have been available to perform the difficult math problems. These findings suggest that math anxiety exerts an online effect on students' math performance particularly in highly demanding test situations because anxieties deplete WM resources (Beilock, 2008).

A related approach in the literature examining the impact of math anxiety on math performance in older students has examined WM as an individual difference variable. Simply put, some people have more of this cognitive capacity than others (Engle, 2002). Typically, the more WM capacity people have, the better their performance on academic tasks such as problem solving and reasoning (Engle, 2002) and the better they are at regulating their emotional experiences (Schmeichel & Demaree, 2010; Schmeichel, Volokhov, & Demaree, 2008). Thus, one might imagine that those with higher WM would be best equipped to deal with the difficulties associated with anxiety in educational settings. Lower-WM individuals, on the other hand, are thought to have limited capacity for problem computations to begin with, which means that anxiety-induced consumption of WM may shrink this available capacity below the level needed to successfully solve difficult math problems.

However, there is also a less intuitive prediction that can be made regarding how math anxiety might relate to the math performance of individuals lower and higher in WM. Namely, higher-WM individuals might be *more* prone to poor performance as a function of math anxiety. If high-WM students rely heavily on problem-solving strategies that load WM and math anxiety specifically targets the WM system, this may make high-WM students' performance susceptible to the impact of anxiety. In contrast, low-WM students may rely on shortcuts or heuristic strategies to solve math problems precisely because they cannot hold demanding problem-solving algorithms in WM. Under this view, if anxiety negatively impacts the WM system, low-WM students would in a sense have little or nothing to lose compared with high-WM students.

There is actually strong support for this less intuitive idea in research with adults examining how performance pressure interacts with WM. For instance, Beilock and Carr (2005) asked high and low-WM individuals to complete a block of math problems under a low-pressure condition and then under a high-pressure condition, which was meant to place individuals under a heightened state of anxiety. In the absence of pressure, students with high WM outperformed low-WM students in their problem-solving accuracy. However, when individuals were asked to solve a similar block of math problems under high pressure, high-WM students' math performance fell to the level of those with low WM. Importantly, these effects were limited to difficult math problems that required the most WM. In subsequent work, Beilock and DeCaro (2007) showed that both low-WM and high-WM students reported the same level of state anxiety during math problem solving, suggesting that it was differential reliance on WM rather than different perceptions of the situation that drove these patterns of performance (although see Gimmig et al., 2006 for evidence that high-WM students can perform poorly under pressure because of their anxious perception of the situation).

Based on these findings, we hypothesized that young children who are high in WM may be most vulnerable to performing poorly in math as a function of self-reported math anxiety. Hence, we predicted that if math anxiety exists among our young study sample, it would be negatively associated with math achievement particularly among high-WM children (Ackerman, 1988; Barrouillet & Lépine, 2005). Furthermore, to establish that our math anxiety measure relates specifically to math achievement and is not simply a proxy measure for general academic anxiety, we asked students to complete a measure of reading achievement as well as a measure of math achievement. Our prediction was that higher-WM children would show a negative relation between self-reported math anxiety and math but not reading achievement.

METHOD

Participants

Children from five public schools in a large urban school district participated in this study. This research was conducted as part of a larger study investigating the affective factors that impact early learning (Beilock, Gunderson, Ramirez, & Levine, 2010). Parental consent forms were obtained from each child participating in the study. A total of 162 signed parental consent forms were returned. From this sample, 94 participants were first-grade students (47 male, 47 female) and 68 were second-grade students (28 male, 40 female). The average age was 7; 1 ($SD = 7.08$ months), with a range from 5; 4 to 8; 10. The mean household income was $36,985 ($SE = 2.140$). The poverty line for a household of four in the United States, which is set annually by the U.S. Department of Health and Human Services, was $22,050 in 2009 (the year our data were collected).

Tasks

The following tasks were administered to all children in the study. It should be noted that although our scoring of these tasks did not take grade level into account, we control for grade level in our analyses.

Total digit span. As a measure of WM, we used the Digit Span subtest score, which is a composite of the forward and backward span tests on the Wechsler Intelligence Scale for Children-Third Edition (WISC-III; Wechsler, 1991). The forward digit span task is a commonly used measure of immediate verbal short-term memory, and the backward digit span task has been generally used as measure of executive attention in neuropsychological and developmental research. We chose to use the combined forward and backward digit span scores (Total Digit Span) because WM is thought to be composed of memory processes, measured by forward digit span, and executive attention processes, measured by backward digit span (Engle, 2002).

In the forward digit span task, the child is read a series of digits (e.g., ‘‘4, 9, 2’’) at a rate of one digit per second and is asked to immediately repeat the digits back. If they do this successfully across two trials of the same set size, they are given a set size that is one digit longer. The set size increases by one unit until the child fails on both trials at a particular set size. The possible set sizes for the forward digit span ranged from two items up to eight items. The backward digit span task is a more challenging variation that also involves presenting digits at a rate of one digit per second but then requires the child to recall the presented items in the reverse order. For example, if the experimenter says ‘‘6, 2, 9’’ the child is supposed to repeat back ‘‘9, 2, 6.’’ The set size for the backward digit span task begins at two items and goes up to a maximum of seven items. For the purpose of this study, the Total Digit Span score consisted of the combined number of correct trials on the forward and backward digit span tasks. Although the digit span task uses number words as stimuli, it has been shown to be a measure of phonological memory span rather than a measure of mathematical problem-solving ability (Anderson, 2007). Additionally, children’s digit span scores were not related to math anxiety in our data (see Table 1 for descriptive statistics for both first- and second-grade levels).

Woodcock-Johnson III Applied Problems subtest. As a measure of math performance, we administered the Woodcock-Johnson III Applied Problems subtest (Woodcock, McGrew, & Mather, 2001), a nationally normed, comprehensive test battery used for assessing the academic achievement skills of individuals aged 2 through 90 years. On the Applied Problems subtest, students are presented with increasingly difficult math-related word problems that require comprehension of the nature of the problem, identification of relevant information, and performance

TABLE 1
Overall and Grade-Level Descriptive Statistics for Total Digit Span, Math Achievement, Reading Achievement, Math Anxiety, and Child Age

	All students (N = 154) *Mean (SD)*	*First grade (N = 88)* *Mean (SD)*	*Second grade (N = 66)* *Mean (SD)*
Total Digit Span	10.15 (2.49)	9.58 (2.42)	10.91 (2.40)
Math W Score	451.23 (18.56)	443.57 (16.29)	461.44 (16.55)
Reading W Score	436.79 (34.44)	422.11 (31.73)	456.36 (27.64)
CMAQ	8.07 (2.86)	8.28 (2.89)	7.79 (2.81)
Child Age	7.05 (0.59)	6.68 (0.46)	7.53 (0.30)

Note. First-grade students scored significantly below second-grade students ($ps < .05$) on all measures except for math anxiety (CMAQ), on which there was no significant grade difference.

of relevant calculations. For instance, some of the early problems on this subtest involve single-digit arithmetic as well as identifying the correct time on a clock, whereas later problems require children to solve two-digit arithmetic problems, money calculations, and calculations involving simple fractions. Testing continues until both a basal (six items in a row correct) and ceiling (six items in a row incorrect) are established. Because of experimenter error, a few participants only completed between three and five items for the basal or ceiling level. These participants were scored as if they had completed the full basal or ceiling level. Moreover, excluding these participants did not alter the significance of the results reported below in any way. For all analyses involving the Applied Problems subtest, we used the W score, a transformation of the raw score into a Rasch-scaled score with equal intervals (a score of 500 is the approximate average performance of a 10-year-old).

Woodcock-Johnson III Letter–Word Identification subtest. Reading performance was assessed using the Letter–Word Identification subtest of the Woodcock-Johnson III Tests of Achievement. This subtest measures the ability to identify letters and words at increasing difficulty levels. It is administered using the same basal and ceiling procedure as the Applied Problems subtest. The W score was used in all analyses involving the Letter–Word Identification subtest.

Child Math Anxiety Questionnaire (CMAQ). Our eight-item measure of math anxiety was adapted from the Mathematics Anxiety Rating Scale for Elementary children (Suinn et al., 1988), which was constructed for fourth through sixth graders. In most cases, the questions retained the original content but used math problems that were age appropriate. Some items asked children their attitudes about solving particular problems that were drawn from mathematics-teaching workbooks for children in the early elementary grades (e.g., ''There are 13 ducks in the water, there are 6 ducks on land, how many ducks are there in all?''). Other items asked children about specific situations they might be confronted with at school concerning math (e.g., ''being called on by a teacher to explain a math problem on the board''). We asked children to make their responses about each question using a sliding scale that featured a calm face on the far right, a seminervous face in the middle, and an obviously nervous face on the far left (see Appendix). We encouraged all children to use the full continuum of the scale, which allowed us to derive numerical scores in between the faces. The numerical scale (which was invisible to children) ranged from 1 to 16. We used the word ''nervous'' when probing children for their attitude and began the math anxiety session by giving students examples of what it means to be nervous (e.g., ''looking down from the top of a really tall building''). Each child's CMAQ score was calculated by taking an average of the eight items.

Using Cronbach's alpha, reliability for our eight-item math anxiety scale was found to be .55. Although a coefficient alpha (Cronbach, 1951) of .70 is generally considered ''acceptable'' in most social science research situations, it is important to highlight that an alpha coefficient below .70 is quite common in published studies investigating attitudes among primary school children (Erdley, Cain, Loomis, Dumas-Hines, & Dweck, 1997; Giles & Heyman, 2003). One reason is that Cronbach's alpha is highly influenced by the number of items in a scale. Most early elementary scales must be shorter to accommodate time restrictions placed on school research so that children do not miss too much classroom time and so they do not get fatigued. To keep our testing session as short as possible, our measure of math anxiety in children was composed of only eight items (compared with adult and adolescent math anxiety measures that typically contain 26 to 95 items).

Procedure

All sessions were conducted one-on-one with an experimenter and took place during the first 3 months of the school year. Each child was tested in a quiet area of the school. Testing was spread across two sessions during the course of 2 to 7 days. Students were assessed on achievement measures during 1 day (Session 1) and on math anxiety on a separate day (Session 2) to minimize the influence of anxiety measures on achievement, and vice versa.

The achievement session began with an introduction that the child would be playing some number and letter games. The three achievement measures were administered in one of two orders, counterbalanced across children. Half of the children completed the Woodcock-Johnson Letter–Word Identification task, followed by the Woodcock-Johnson Applied Problems task, followed by the WISC-III Digit Span subtest. The other half of the children completed the tasks in the reverse order. These three tasks combined took an average of 15 minutes to administer.

For the math anxiety session, children were given the CMAQ embedded within other questionnaires for a larger study. The CMAQ was described as a question game in which the experimenter would ask the child a series of questions for which the child could answer using the sliding scale. Before beginning the CMAQ, all the children were given a series of instructions to help them understand the meaning of the word ''nervous'' and to orient them about how to use the sliding scale. Children also were given a few example questions and provided with feedback about how to properly respond with the sliding scale to ensure that students had an idea of what it means to be nervous. After children completed each session, they were thanked for their participation and escorted back to their classroom.

RESULTS

Our final sample consisted of 88 first-grade students (42 male, 46 female) and 66 second-grade students (27 male, 39 female) for a total sample size of 154. Five additional participants were removed from our analyses because they had a score missing on one or more of our four measures (i.e., Total Digit Span, Woodcock-Johnson III Applied Problems test, Letter–Word

Identification, CMAQ). Three additional participants shown to be highly influential data points using Cook's distance (Cook, 1977) in our primary regression analysis described below were also removed.

Child Math Anxiety Questionnaire

We calculated children's responses on the CMAQ using a mean across all items. Children's responses on the CMAQ did not differ as a function of grade, $t(152) = 1.042$, $p > .25$, or gender, $t(152) = 1.520$, $p > .10$. As shown in Figure 1, children's responses on the CMAQ were normally distributed with a mean of 8.07 ($SD = 2.86$). Thus, even in early elementary school, some students reported feeling nervous about various situations involving math. Importantly, CMAQ scores did not correlate with children's digit span scores while controlling for grade level, $r(151) = .021$, $p = .80$. Nor did children's CMAQ scores correlate with family's annual gross income, $r(133) = .047$, $p = .589$. Thus, children as early as first and second grade reported feeling ''nervous'' for various math-related situations, but these feelings of nervousness were not associated with our measure of WM or traditional proxies of parental involvement.

Relation Between Math Anxiety, WM, and Math Achievement

We began by regressing children's math achievement on their math anxiety, WM (using Total Digit Span), and the interaction of math anxiety × WM. We also included children's grade level as a covariate. There was a significant main effect of grade ($\beta = .335$, $t = 5.474$, $p < .01$) and WM ($\beta = .869$, $t = 4.931$, $p < .01$), but not math anxiety ($\beta = .420$, $t = 1.726$, $p > .05$). However, the main effect of WM was qualified by a significant math anxiety × WM interaction ($\beta = -.658$, $t = -2.242$, $p = .026$). Figure 2 plots the predicted math achievement of children who are ±1 *SD* from the mean in math anxiety and ±1 *SD* from the mean in WM. Note that WM and math

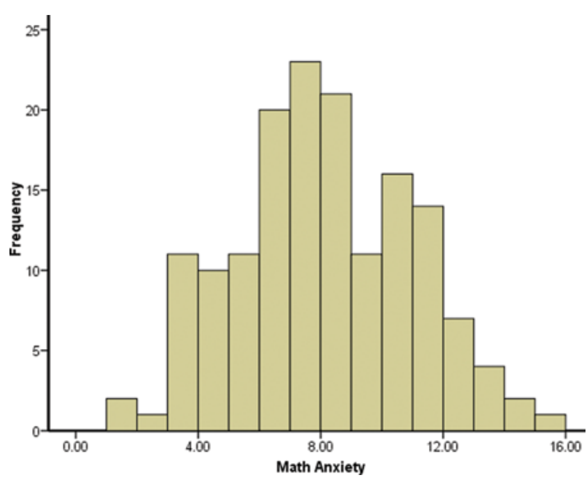

FIGURE 1 Histogram displaying the distribution of children's CMAQ scores. (Color figure available online.)

anxiety in Figures 2 and 3 are treated as continuous variables, but are plotted at ±1 *SD* for descriptive purposes.

As shown in Figure 2, the relation between math anxiety and math achievement is quite different when plotted as a function of individual differences in WM. For students relatively higher in WM, there was a pronounced negative relation between math anxiety and math achievement. This relation was not evident among students relatively lower in WM.

The above results are in line with findings in the adult literature showing that individuals who rely more heavily on WM when solving math problems (i.e., those with high levels of WM) are most impacted by anxiety because worries about the situation likely deplete the cognitive resources that support their math performance (Beilock, 2008). If this explanation applies to our results as well—that is, if math anxiety disrupts the performance of students who use computationally difficult problem-solving strategies—then our predicted WM × math anxiety interaction should be especially apparent for more difficult problems that likely require more WM and encourage more varied problem-solving strategies.

Although we chose to use a standardized measure of math performance (Woodcock-Johnson Applied Problems) rather than to experimentally manipulate problem demand, we nevertheless sought to examine children's performance on higher- versus lower-demand problems within this standardized task. To do this, we selected a section of the Woodcock-Johnson math achievement test that a large majority (more than 97%) of the children encountered (Items #15–24) and excluded the four participants who did not encounter these problems (bringing the total sample size for this analysis to $N = 150$). Because the Woodcock-Johnson is organized progressively, so that items appearing later in the test are more challenging than items appearing earlier, we divided these selected items in half as a method of defining easy problems (Items 15–19) versus

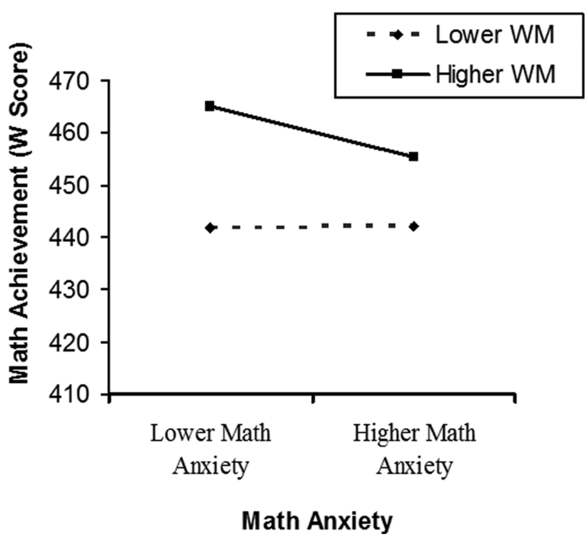

FIGURE 2 Students' math achievement as a function of individual differences in working memory (WM) and math anxiety. WM and math anxiety are plotted at 1 *SD* above and below the mean. Children relatively higher in WM showed a pronounced negative relation between math anxiety and math achievement.

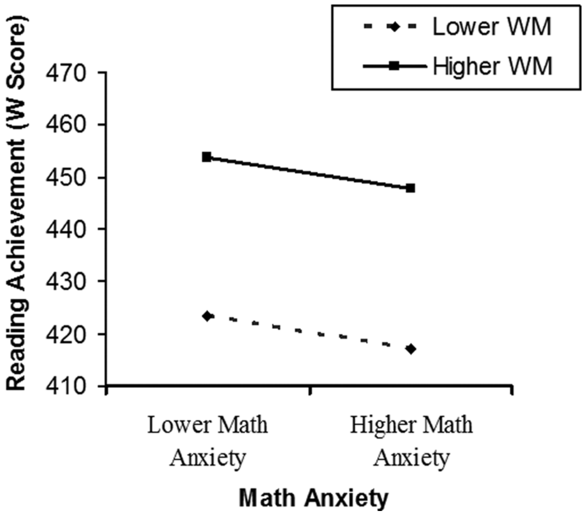

FIGURE 3 Students' reading achievement as a function of individual differences in working memory (WM) and math anxiety. WM and math anxiety are plotted at 1 *SD* above and below the mean. Children relatively higher in WM showed higher reading achievement than low-WM children. However, these differences do not appear to be dependent upon math anxiety.

difficult problems (Items 20–24).[1] We then re-examined children's performance on easy and hard problems separately, considering easy versus hard problems to be a proxy for low versus high WM-demanding problems.

When we reran our main analysis using performance on the easy items as a dependent variable (DV), we found a main effect for WM ($\beta = .600$, $t = 2.693$, $p < .01$) but not for math anxiety ($\beta = .350$, $t = 1.146$, $p > .05$) or grade ($\beta = .058$, $t = 0.746$, $p > .05$), and we did not find a significant WM × math anxiety interaction ($\beta = -.329$, $t = -0.894$, $p > .05$). By contrast, when we reran our main analysis using performance on the hard items as a DV, we found a main effect of grade ($\beta = .210$, $t = 2.83$, $p < .01$), WM ($\beta = .828$, $t = 3.886$, $p < .01$), math anxiety ($\beta = .590$, $t = 2.021$, $p = .045$), and the critical two-way WM × math anxiety interaction ($\beta = -.770$, $t = -2.189$, $p = .030$). In other words, when high-WM children have high math anxiety, their performance is specifically impaired on those math problems that typically require more complex, WM-demanding strategies.

[1]The hard items differed from easy items in several important ways. In terms of subtraction problems, hard items depicted images of objects that were scattered randomly (e.g., crayons piled on top of each other in an unorganized fashion) making them difficult to count. In addition, these problems contained two-digit minuends. In contrast, easy subtraction items depicted objects that were well organized in a linear fashion (e.g., pennies ordered along a line) and contained single-digit minuends. In terms of addition problems, hard items were worded to prime a maximum problem-solving approach (i.e., $3 + 6$), whereas easy addition problems were worded to prime a minimum problem-solving approach (i.e., $6 + 3$). This difference in wording is significant as a shift from maximum to minimum strategies is associated with an increase in ease of processing and fewer errors (Geary, Bow-Thomas, & Yao, 1992; Geary, Hoard, Byrd-Craven, & DeSoto, 2004; Siegler, 1987). Lastly, hard items asked children to read an analog clock, which required children to recall specific knowledge on how to tell time, whereas easy items simply asked children to point to a clock that displayed a specific time (e.g., 7:00), which only involved the recognition of specific numbers and clock configurations (e.g., 7).

Relation Between Math Anxiety, WM, and Reading Achievement

To account for the possibility that our measure of math anxiety was tapping general test- or school-related anxiety, we also asked whether math anxiety was related to children's reading achievement. Importantly, when we reran the above analysis with reading achievement as the outcome variable, we found a significant effect of grade ($\beta = .373$, $t = 5.823$, $p < .01$) and WM ($\beta = .434$, $t = 3.43$, $p < .01$) but not math anxiety ($\beta = -.099$, $t = -0.443$, $p > .05$). In addition, we did not find the critical interaction of math anxiety × WM ($\beta = .011$, $t = 0.041$, $p > .05$; see Figure 3). Thus, children's CMAQ scores relate to math achievement and not reading achievement, suggesting that our measure of math anxiety carries specific implications for math achievement per se rather than for general academic achievement.

DISCUSSION

A growing body of evidence highlights the importance of taking into account both cognitive and affective factors in understanding students' academic achievement. However, most of the research on the relation of math anxiety and math achievement has been carried out on middle school to college-age students. The work reported here shows that a self-report measure of math anxiety is already associated with math achievement in children as early as first and second grade. Moreover, our math anxiety measure was not related to children's reading achievement, suggesting it is not just a proxy for general academic anxiety.

Importantly, the association between math anxiety and math achievement is not present in all first- and second-grade students. Rather, the negative relation between math anxiety and math achievement is present among children who are relatively high in WM but not among those who are relatively low in WM. These results mirror findings in adults showing that the impact of math anxiety on math achievement is specific to math performance for those with higher levels of WM (Beilock & Carr, 2005; Beilock & DeCaro, 2007).

There are several possible explanations for the interaction between math anxiety and level of WM. The explanation we favor is that children who rely more heavily on WM when solving math problems (i.e., those with high levels of WM) are most impacted by math anxiety because worries about the situation deplete or interfere with the cognitive resources that support their math performance (Beilock & Carr, 2005; Beilock & DeCaro, 2007; Vukovic, Kieffer, Bailey, & Harari, 2013). Indeed, this phenomenon is likely to occur in children as well as adults, because WM strongly influences problem strategies and math performance even at a young age (Barrouillet, Bernardin, & Camos, 2004; Barrouillet & Lépine, 2005; Gavens & Barrouillet, 2004; Lépine, Barrouillet, & Camos, 2005).

High-WM children, for example, are more likely to use direct retrieval as opposed to finger counting when solving math problems (Barrouillet & Lépine, 2005), and retrieval efficiency is particularly disrupted by interference (Barrouillet et al., 2004; Gavens & Barrouillet, 2004; Lépine et al., 2005; Mattarella-Micke & Beilock, 2010). In contrast, low-WM children's math achievement may remain relatively unaffected by math anxiety precisely because they use less sophisticated (and less WM-demanding) problem-solving strategies. Hence, the association between math anxiety and math achievement may be present among high-WM (but not low-WM) children because math anxiety disrupts the resources that high-WM children rely on to retrieve basic facts from long-term memory and to inhibit competing answers (Geary et al., 2004). Math anxiety may make high-WM children more prone to retrieval interference, resulting in a slower and less efficient retrieval process. It is also possible that math anxiety-induced disruption of WM leads high-WM children to switch their problem-solving strategies as a means of circumventing the burden of math anxiety on WM. Indeed, past work with adults (Beilock & DeCaro, 2007) and children (Barrouillet & Lépine, 2005) suggests that factors that constrain WM (e.g., anxiety during math tests, operand size) lead students to switch to less WM-demanding, less successful problem-solving approaches.

There are however, several other alternative accounts for the relationship we found between math anxiety and WM. For instance, higher-WM children may simply get farther along on the math test than lower-WM children, and this could cause them to encounter more WM-demanding problems that are specifically impaired by math anxiety. However, this does not seem to be the case, as we found an interaction between WM and math anxiety even on problems that virtually all students in our sample encountered.

Another possibility is that higher-WM children are simply more emotionally aware of their math difficulties, which would lead these children to give more accurate self-reports of math anxiety (leading to our observed correlation between math anxiety and math performance among high-WM students specifically). Although this is an interesting idea, there is research suggesting that, when presented with negatively valenced images, when given negative feedback about their abilities, or when provoked toward anger, higher-WM individuals are actually less likely than their lower-WM counterparts to report experiencing negative emotions or to respond in an emotional manner (Hofmann, Gschwendner, Friese, Wiers, & Schmitt, 2008; Joormann & Gotlib, 2008; Schmeichel & Demaree, 2010; Schmeichel et al., 2008). Thus, one could also imagine that lower-WM (rather than higher-WM) children would be more aware of their low ability and better able to accurately report on their math difficulties and anxiety. Future research is needed to explore these ideas.

Further support for the WM disruption account that we favor comes from our examination of performance as a function of problem-computational difficulty (e.g., easy vs. hard). If the WM-disruption account is in fact at work, then we should show a WM $\times$ math anxiety interaction only among problems that are computationally demanding. This is exactly what we found. Our results align well with work examining the impact of anxiety on math performance in the adult literature, which typically reports that performance on the most computationally demanding problems is affected by math anxiety (Ashcraft & Kirk, 2001; Beilock & Carr, 2005; Beilock & DeCaro, 2007). Of course, more direct support for the WM-disruption hypothesis could be provided by simply examining the problem-solving strategies that children employ as a function of individual differences in WM and math anxiety. However, our use of a standardized task as a measure for math performance precluded asking children to explicitly report their problem-solving strategies as this would have disrupted the validity of the of the task.[2]

[2]One could also posit that there are some top-notch students (i.e., those with higher WM) who experience math anxiety because they perform well in most domains (i.e., reading) except math. If top-notch students who perform well in the domain of reading are developing math anxiety because of their particularly poor performance in math, then we would expect that these students would show a stronger negative relationship between math ability and math anxiety than those with low reading ability. To evaluate this possibility, we performed a median split of reading ability on our students with higher WM. We found that among students with lower reading ability, math ability and math anxiety were moderately associated, $r(32) = -.402$, $p = .018$, but this was not the case among children with higher reading ability, $r(34) = -.201$, $p = .239$. In other words, the pattern of results was the opposite of that predicted by this alternative interpretation of the relation between WM, math anxiety, and math achievement.

Given the correlational nature of the current work, we cannot make a causal claim about the relationship between math anxiety and math performance, nor can we conclusively determine the specific mechanism that accounts for why high- but not low-WM children demonstrate a negative relationship between math anxiety and math ability. Although it is not possible to experimentally manipulate trait math anxiety, future studies that examine young children's responses to stressful, math-testing situations may help to determine the causal relations between math anxiety, WM, and performance in young children.

Undoubtedly, cognitive factors like WM play an important role in academic achievement by themselves as well (Gathercole, Alloway, Willis, & Adams, 2006). Our data are consistent with this notion as Figures 2 and 3 show striking WM differences in both math and reading performance, suggesting the utility of using WM as a predictor of skill acquisition and as an index of which children may potentially encounter academic difficulties. The aforementioned results bolster the significance of the work reported here as it suggests that young students who are quite competent may show suboptimal math performance because math anxiety usurps their potential cognitive advantage.

Thus, our data suggest that individual differences in cognitive factors such as WM and math knowledge do not tell the whole story about why many students perform poorly in math. Educators should not only consider math learning in terms of concepts, procedures, math curricula, and instruction but also the emotions and anxieties children may bring to the learning situation.

Even though this study puts forth an account of how math anxiety can affect math performance online while children are solving math problems, we recognize that math anxiety may also have an effect on math performance through an avoidance of math tasks (Hembree, 1990; Krinzinger et al., 2009) perhaps by reducing expectations of success and the subjective value of math (Eccles et al., 1983; Wigfield & Meece, 1988) as well as by changing the achievement goals that students adopt in the domain of math (Butler, 1999; Smiley & Dweck, 1994). Hence, early math anxiety may lead to a snowball effect that exerts an increasing cost on math achievement by changing students' attitudes and motivational approach toward math, increasing math avoidance behaviors, interfering with cognitive processing when they are solving difficult math problems, and ultimately reducing math competence. Avoidance and motivational factors may become more prevalent later in schooling when students have to rely more on intrinsic forms of motivation and are given more autonomy in choosing their math courses, college majors, and career paths (e.g., National Mathematics Advisory Panel, 2008; Ryan & Pintrich, 1997).

Indeed, prior work suggests that math anxiety is associated with lower enrollment in math-intensive majors during college (Hembree, 1990). This can be particularly problematic as math anxiety is endemic in college students who choose a career path in elementary school education (Hembree, 1990), and previous work suggests that math-anxious teachers and parents exert a significant influence on students' math achievement (Beilock et al., 2010; Vukovic, Roberts, & Green Wright, in press). These findings suggest that addressing math anxiety at the teacher level may be an effective starting point in ameliorating math anxiety in young children and improving children's math achievement.

Of course, the effectiveness of interventions at the teacher level (Ping et al., 2011; Simon & Schifter, 1993) may work best when used in conjunction with interventions at the student level as well (Betz, 1978; Hendel & Davis, 1978; Vance & Watson, 1994). Instruments such as the CMAQ used in the current work may provide an effective tool in helping to identify young children whose insecurities about math may prevent them from reaching their intellectual zenith.

Because previous studies have examined math anxiety interventions primarily among college students, it is important to develop interventions that are specific to young child populations that are initially developing math anxiety. Our work suggests that making students aware of alternative problem-solving techniques that can withstand the impact of math anxiety on WM may be one such way to lessen the math anxiety–math performance relationship. Such teaching activities, though infrequent in the earliest grades, have been shown to improve the performance of low-achieving students (Moely et al., 1992).

In conclusion, our results highlight the potential of math anxiety to negatively impact children's math achievement as early as first and second grade. The finding that children who are higher in WM may be most susceptible to the deleterious effects of math anxiety is particularly worrisome because these students arguably have the greatest potential for high achievement in math. Investigating the development of math anxiety from the earliest grades will not only increase our understanding of the relation between math anxiety and math performance across the school years but is also a critical first step in developing interventions designed to ameliorate these anxieties and increase math achievement.

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APPENDIX

Child Math Anxiety Questionnaire Items

1. How do you feel when taking a big test in your math class?
2. How would you feel if you were given this problem? *There are 13 ducks in the water. There are 6 ducks in the grass. How many ducks are there in all?*
3. How would you feel if you were given this problem? *You scored 15 points. Your friend scored 8 points. How many more points did you score than your friend?*
4. How do you feel when getting your math book and seeing all the numbers in it?
5. How do you feel when you have to solve $27 + 15$?
6. How do you feel when figuring out if you have enough money to buy a candy bar and a soft drink?
7. How do you feel when you have to solve $34 - 17$?
8. How do you feel when you get called on by the teacher to explain a math problem on the board?