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Math Anxiety: Past Research, Promising Interventions, and a New Interpretation Framework

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Mathematics anxiety is a pervasive issue in education that requires attention from both educators and researchers to help students reach their full academic potential. This review provides an overview of past research that has investigated the association between math anxiety and math achievement, factors that can cause math anxiety, characteristics of students that can increase their susceptibility to math anxiety, and efforts that educators can take to remedy math anxiety. We also derive a new Interpretation Account of math anxiety, which we use to argue the importance of understanding appraisal processes in the development and treatment of math anxiety. In conclusion, gaps in the literature are reviewed in addition to suggestions for future research that can help improve the field's understanding of this important issue.

Success in mathematics requires that students see math as a sensible, useful, and worthwhile endeavor (Common Core States Standards Initiative, n.d.). Unfortunately, many students do not hold such a productive disposition because of a deep fear of math. In this article, we discuss math anxiety as an important barrier to success in math. Drawing upon research from psychology, education, and neuroscience, we highlight the differing theories of why math anxiety develops and how it impacts performance, discuss interventions that have been successful in increasing math performance in higher-math-anxious individuals (i.e., students with higher levels of math anxiety), and provide suggestions for what we view to be new important avenues for future research. Notably, we also synthesize disparate bodies of work within the math anxiety literature to propose a new Interpretation Account of how math anxiety develops, which we use to address several areas of conflicting results within the literature.

WHAT IS MATH ANXIETY?

Math anxiety refers to feelings of fear, tension, and apprehension that many people experience when engaging with math (Ashcraft, 2002). Math anxiety is thought to be a trait-level anxiety and is distinguishable from both test anxiety (Kazelskis et al., 2001) and state anxiety (Hembree, 1990). For a math anxious student, math creates more than a feeling of dislike or worry; it also affects physiological outcomes such as heart rate, neural activation, and cortisol (Faust, 1992; Lyons & Beilock, 2012b; Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011; Pletzer, Kronbichler, Nuerk, & Kerschbaum, 2015; Sarkar, Dowker, & Cohen, 2014). Notably, higher-math-anxious students show increased heart rates (Faust, 1992) and, when cued with an upcoming math task, show neural activations similar to those found when individuals experience physical pain (Lyons & Beilock, 2012b). Math anxiety has even been thought to operate similar to a phobia (Hembree, 1990; Pizzie & Kraemer, 2017), as brief exposure to math stimuli creates a behavioral disengagement bias similar to a fear-conditioned stimulus (Pizzie & Kraemer, 2017).

The most common way to identify math anxiety is through self-report questionnaires that ask students to indicate how they feel about situations that involve math, though recent work has employed experience sampling surveys (Bieg, Goetz, Wolter, & Hall, 2015; Goetz, Bieg, Lüdtke, Pekrun, & Hall, 2013). As math anxiety is a continuous construct, there is no clear cutoff point on any measure that divides anxious individuals from nonanxious individuals. Most researchers choose to treat math anxiety as a continuous variable, often plotting scores at $\pm$ 1 *SD* of the sample mean (e.g., Maloney, Ramirez, Gunderson, Levine,

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& Beilock, 2015; Ramirez, Chang, Maloney, Levine, & Beilock, 2016); create extreme groups using the upper and lower quartiles of the sample distribution (e.g., Maloney, Risko, Ansari, & Fugelsang, 2010); or divide their sample based on ± 1 *SD* of the sample mean and work with low (−1 *SD*), medium (mean), and high (+1 *SD*) math anxiety groups (e.g., Ashcraft & Kirk, 2001).

Although there are numerous ways that math anxiety is measured, a consistent finding is that math anxiety is highly prevalent. In the United States, an estimated 25% of 4-year college students and up to 80% of community college students report moderate to high levels of math anxiety (Yeager, as cited in Chang & Beilock, 2016). Across the 65 countries and economies that participated in the 2012 Programme for International Student Assessment (PISA), 33% of 15-year-old students, on average, reported feeling helpless when solving math problems (Organization for Economic Co-operation and Development [OECD], 2013). Worldwide, increased math anxiety is linked to lower success in math both within and across countries (Foley et al., 2017; Lee, 2009). For example, in all but one of the 65 education systems that participated in PISA in 2012, students with higher levels of math anxiety showed lower levels of math performance compared to their lower-math-anxious peers (OECD, 2013). On average across OECD countries, for every one-unit difference in country-level math anxiety, there is an expected *73-point* score gap on a standard math assessment (which corresponds to a large effect size, $d = .81$; Foley et al., 2017).

HOW IS MATH ANXIETY LINKED TO MATH ACHIEVEMENT?

One of the most robust findings in the field of math anxiety research is its relation to lower math achievement (for a meta-analysis, see Ma, 1999). Two frameworks have traditionally been offered to explain the connection. The first argues for a Disruption Account, or that math anxiety causes people to underperform in mathematics. The second framework follows a Reduced Competency Account, which suggests that math anxiety is a proxy for poor math ability. We examine evidence for these two viewpoints next.

Disruption Account

The most widely held theory posits that math anxiety causes worse math performance through a transient reduction in the cognitive resources that are needed for success in math (i.e., working memory [WM]). WM is a short-term memory system that controls, regulates and actively maintains a limited amount of information relevant to the task at hand (Engle, 2002; Miyake & Shah, 1999). When doing math, we use WM to retrieve information needed to solve the math problem (e.g., multiplication products, order of operations), keep pertinent information about the problem salient, and inhibit irrelevant information. Intrusive thoughts and ruminations, however, can disrupt WM (Eysenck & Calvo, 1992).

Math anxiety is believed to cause negative thoughts and ruminations, often about the consequences of failure in the math task (Ashcraft & Kirk, 2001). Thus, when higher-math-anxious people engage with math, they are essentially doing two things at once: (a) dealing with negative thoughts and ruminations and (b) attempting to solve the math problems at hand. Because success in math is so often dependent on WM resources (Ashcraft, Donley, Halas, & Vakali, 1992; Lefevre, DeStefano, Coleman, & Shanahan, 2005; Lemaire, Abdi, & Fayol, 1996), the online burden of affective concerns has been argued to handicap WM, which in turn affects a person's ability to effectively solve math problems. According to Ashcraft et al. (1992), the correlation between math anxiety and performance has less to do with math competency and more to do with worries disrupting critical WM resources.

Evidence for this Disruption Account of math anxiety originates from research investigating differences in basic arithmetic performance between students with high and low math anxiety. Specifically, higher-math-anxious individuals are slower and make more errors during basic arithmetic problems, but only for problems that require a carry operation, which is known to load heavily on WM (Ashcraft & Faust, 1994; Faust, Ashcraft, & Fleck, 1996). Pletzer et al. (2015) presented neural evidence consistent with a Disruption Account, in a study that reports a difference in neural efficiency between high- and low-math-anxious students.

Pletzer et al. (2015) described neural efficiency as activating areas of the brain necessary for solving math problems while deactivating other competing networks that are unrelated to math. Low-math-anxious students showed this efficiency with increased activation in the dorsolateral prefrontal cortex (a sign of engagement in cognitive and attentional control), paired with decreased activation in the default mode network (a sign of decreased self-reflection and emotional processing). However, higher-math-anxious students showed increased activation in the dorsolateral prefrontal cortex but also less deactivation of the default mode network. Important to note, these group differences were found even though performance was equivalent across higher- and lower-math-anxious students. Put simply, whereas lower-anxious students show only task-relevant neural activation, math-anxious students show both task-relevant and task-irrelevant activation.

Further evidence for the role of affective concerns in math-anxious students' performance comes from research by Sarkar et al. (2014), in which a transcranial direct current stimulation (tDCS) was administered to the dorsolateral prefrontal cortex of higher and lower math anxious students before solving math problems. The authors theorized that applying tDCS to the dorsolateral prefrontal cortex, a frequent target for emotional control in stimulation studies (Boggio, Zaghi, & Fregni, 2009), would enhance emotional control in participants, which could lead them to perceive numerical tasks as less negative/stressful. The results showed, as predicted, higher-math-anxious students who received the tDCS solved math problems faster and showed a greater recovery of the stress-related hormone cortisol than participants who received the control stimulation. These findings further implicate affective concerns as an obstacle that math-anxious students must overcome to improve WM efficiency and their performance in math (Sarkar et al., 2014).

WM plays an important moderating role in the relation between math anxiety and math achievement. In a series of studies, Ramirez and colleagues (Ramirez et al., 2016; Ramirez, Gunderson, Levine, & Beilock, 2013; see also Vukovic, Kieffer, Bailey, & Harari, 2013) examined how individual differences in math anxiety and WM might relate to student performance on a standardized test of math achievement. Although one could expect that high-WM students would be the least impacted by math anxiety—after all, they have more of this necessary cognitive resource—the results revealed that these students may be the *most* susceptible to the impact of math anxiety.

Even though this finding seems counterintuitive at first, Ramirez and colleagues explained it as follows: People who are higher in WM capacity tend to rely on strategies that are highly dependent on WM to execute. When these people experience negative thoughts that co-opt their WM resources, they no longer have the WM needed to complete their strategies and performance suffers. Their lower-WM-capacity peers, on the other hand, tend to rely on problem-solving strategies that are less dependent on WM, so anxiety has less of a disruptive affect. Other research has found evidence of this particular finding through not only longitudinal research in second- and third-grade children (Vukovic, Kieffer, et al., 2013) but also large-scale international assessments. For example, PISA data show that the inverse relation between math anxiety and math performance is strongest among the highest achieving 15-year-old students who are likely to also have superior WM performance (Foley et al., 2017; OECD, 2013).

Collectively, these findings provide evidence in support of a Disruption Account where math anxiety impacts performance by triggering negative thoughts and ruminations that co-opt the WM resources necessary for solving math problems. Hence, according to a Disruption Account, the reason that math anxiety relates to lower achievement is because math anxiety *causes* poor math performance/abilities.

Reduced Competency Account

Although Ashcraft and colleagues' Disruption Account of math anxiety represents the dominant account of how math anxiety relates to math achievement, there is also evidence in support of a Reduced Competency Account, which argues that math anxiety is actually the *outcome* of poor math ability. In this account, a student's reduced competency leads to disfluent learning and performance, which then contribute to math anxiety. Math anxiety is thus an outcome of poor math ability. Variations in this Reduced Competency Account have been proposed as an explanation for both the math anxiety–performance link and why individuals develop math anxiety at all (which we address in a different section). A few frameworks have been suggested under a Reduced Competency Account to explain how poorer skills may relate to math anxiety.

The first framework, posited primarily by Maloney and colleagues, is referred to herein as the Numerical/Spatial Difficulties framework. In this framework, individuals start with lower numerical/spatial skills, and as a result they underperform in math. As a result of this underperformance, people become anxious. An additional assumption of the Numerical/Spatial Difficulties framework is that reduced abilities may cause math anxiety, for example, by increasing sensitivity to negative social cues in math (Maloney, 2016).

Evidence in support of the Numerical/Spatial Difficulties view comes from a series of studies in which higher-math-anxious adults were slower to complete simple numerical and spatial tasks, such as counting objects (Maloney et al., 2010), choosing the numerically larger of two single digits (Maloney, Ansari, & Fugelsang, 2011), or imagining what a three-dimensional object looks like when rotated (Ferguson, Maloney, Fugelsang, & Risko, 2015; Maloney, Waechter, Risko, & Fugelsang, 2012). For example, Maloney et al. (2010) asked undergraduate students to identify the number of squares presented on a computer screen (set sizes ranged from 1 to 9). They found that when five or more squares were presented, higher-math-anxious students made more errors and were slower at counting compared to their lower-anxious peers. Similar results were found with other simple numerical and spatial tasks, suggesting that math anxiety may initially arise because of difficulties around numerical and spatial processing (see Maloney, 2016). In a similar vein, event-related potential studies have found neural evidence that higher-math-anxious students may have a less precise understanding of numerical magnitudes (Núñez-Peña & Suárez-Pellicioni, 2014).

Another proposed framework within the Reduced Competency Account suggests that students who have reduced math abilities avoid taking math classes and leveraging opportunities to hone their math skills (e.g., doing math homework, engaging in math classes; Hembree, 1990). This avoidance can cause students to fall even further behind in their math understanding and lead to math anxiety. Consistent with this claim, students who are math anxious report taking fewer math courses (Ashcraft & Kirk, 2001; Hembree, 1988; LeFevre, Kulak, & Heymans, 1992), and math anxiety among adolescent students has traditionally been related to less intent to take math courses (J. S. Eccles, 1984; J. E. Eccles, Adler, & Meece, 1984; Meece, Wigfield, & Eccles, 1990). Further, participation in informal math activities outside of school has been linked to children's math achievement (e.g., LeFevre, Polyzoi, Skwarchuk, Fast, & Sowinski, 2010; Ramani, Rowe, Eason, & Leech, 2015; Skwarchuk, Sowinski, & LeFevre, 2014; Thompson, Napoli, & Purpura, 2017), and it is possible that children with math anxiety may also avoid informal math experiences (although this hypothesis needs to be explicitly tested).

Comparing the Disruption and Reduced Competency Accounts

In summary, the Disruption Account claims that math anxiety causes poor math performance by depleting important WM resources, whereas the Reduced Competency Account suggests that reduced math abilities leads to underperformance and results in math anxiety. The Disruption Account would thus point toward the removal of worries as a guidepost in the development of interventions to treat math anxiety. In contrast, the Reduced Competency Account would predict that the removal of worries would not completely remove performance difficulties, as math-anxious individuals still lack the necessary math skills, especially in the face of more challenging math. These two views make very distinct recommendations for the development of remediation strategies for reducing math anxiety and the possible impact of math anxiety (for an additional review of these accounts, see Carey, Hill, Devine, & Szücs, 2015).

It is important to note that these two classes of theories are not entirely at odds with each other. Specifically, the Reduced Competency class of theories is agnostic as to whether math anxiety can also cause negative thoughts and ruminations that can impact performance. Although we have discussed these two general viewpoints as somewhat opposed to each other, recent work suggests that it is highly likely that the relation between math anxiety and math achievement is bidirectional (Carey et al., 2015). Findings from studies that use functional magnetic resonance imaging (fMRI) to examine differences in brain activation between higher- and lower-math-anxious children during math tasks support both the Disruption Account and the Reduced Competency Account. For example, Young, Wu and Menon (2012) examined children between the ages of 7 and 9 who were tasked with judging whether solved math problems (addition and subtraction) were correct or incorrect while inside an fMRI scanner. During the task, higher-math-anxious children showed more activation in brain regions associated with processing negative emotions and threatening stimuli (i.e., the amygdala), and they showed less activation in brain regions associated with WM (i.e., the dorsolateral prefrontal cortex and the posterior parietal lobe; Young et al., 2012). In addition, higher-math-anxious children also showed reduced activation in posterior parietal cortex regions known to play a critical role in numerical and mathematical cognition.

The finding that math-anxious students show activation both in cognitive control and numerical processing regions suggests that math anxiety is both the cause and the outcome of poor math abilities; these findings support both the Disruption Account and the Reduced Competency Account. Although these two accounts help us understand the *connection* between math anxiety and achievement, in the next section we focus on what *causes* math anxiety itself.

WHAT CAUSES MATH ANXIETY?

A great deal of effort has been expended to understand what causes math anxiety, but this research has yet to produce conclusive answers. As an individual-difference trait, math anxiety is not something researchers can systematically manipulate, so researchers must piece together a collective picture of what causes math anxiety based on several bodies of work across development. Currently, theories designed to explain the development of math anxiety fall broadly into one of three categories: (a) poor math skills, (b) genetic predispositions, or (c) socioenvironmental factors. Next we review the evidence for these dominant accounts, and then present evidence for a new Interpretation Account.

Poor Math Skills

In the previous section, we introduced the Reduced Competency Account, which argues that it is the association between math and numerical/spatial skills that best explains this inverse relation. In this section, we elaborate on this account by reviewing the arguments that math anxiety is actually *caused* by reduced math competency. That is, math anxiety arises from difficulties in numerical and/or spatial processing.

Early evidence for a Reduced Competency Account was found through longitudinal research that argued that math achievement could cause math anxiety. One of the most thorough longitudinal studies of math anxiety was conducted by Ma and Xu (2004), who examined the causal ordering between math anxiety and math achievement using data from the Longitudinal Study of American Youth— a national study that examined student attitudes and achievement across 6 years (from seventh to 12th grade). Math anxiety and math achievement were measured once per year for 5 years, and the authors used these indices to test for cross-lagged effects. The results revealed several important findings.

Ma and Xu (2004) found that higher math anxiety in previous years predicted lower math achievement in subsequent years; however, these effects were small and occurred only in the early grades of junior high. Second, lower math achievement in previous years predicted higher math anxiety in subsequent years. In fact, all of the negative paths from prior math achievement to later mathematics anxiety were significant, considerably larger, and more consistent than the paths from early math anxiety to later math achievement. This result falls well in line with an account that reduced math abilities/skills contribute to math anxiety. A similar set of findings has been found between achievement and math anxiety (Gunderson, Park, Maloney, Beilock, & Levine, 2017), as well as achievement and reading anxiety (Ramirez, Fries, et al., 2017). These studies suggest that early math anxiety is capable of derailing subsequent performance (in line with a Disruption Account). Poor math achievement, however, appears to be a pronounced cause of later math anxiety (in line with a poor math skills view). Once again, these results show that low achievement comes first, but they cannot provide an adequate account for *how* low achievement leads to math anxiety.

Genetic Predispositions

In 2014, Wang and colleagues published the first (and to our knowledge, the only) empirical research study that sought to answer the question of how genetics contribute to math anxiety. The researchers examined math anxiety in a group of twin adolescent siblings and found that genetic factors accounted for approximately 40% of the variation in math anxiety, with child-specific environmental factors accounting for the remaining variation. Wang et al. (2014) posited that math anxiety is influenced by both genetic and nonfamilial environmental risk factors that are also associated with general anxiety, as well as additional independent genetic influences that are associated with math ability. Although these findings underline the important role that genes may play in a student's susceptibility to math anxiety, equally important to understand are the varying socioenvironmental factors that can pair with such genes to cause or exacerbate math anxiety.

Socioenvironmental Factors

A rich literature examining the social and environmental factors of math anxiety has been under investigation for some time now. This body of work looks to students' experiences inside and outside of the classroom as an important determinant in the development of math anxiety.

Home experiences around math. Parents are often children's first educators and a stable source of educational support outside of the classroom. Parents are commonly encouraged to become involved in their child's education by talking about school, supervising homework completion, and holding high expectations of academic success. Although the efficacy of parental involvement in math shows mixed evidence (H. Cooper, Lindsay, & Nye, 2000; Hoover-Dempsey et al., 2001; Patall, Cooper, & Robinson, 2008), one recent study asked if parental involvement might predict children's math achievement through a reduction in children's math anxiety (Vukovic, Roberts, & Green Wright, 2013). To test this hypothesis, researchers measured children's math performance and anxiety as well as parental involvement using a self-report survey. The results indicated that holding high parental expectations and providing strong support at home was associated with a reduction in children's math anxiety, which in turn relates to higher math achievement. However, interpretation of the results of this study has three important caveats: (a) These effects were reported at a single time point rather than longitudinally, (b) none of the other parent involvement factors (i.e., direct support with homework, communicating with child's teacher, homework understanding, etc.) predicted children's math achievement, and (c) the researchers did not measure the parents' own levels of math anxiety.

In a recent study of the intergenerational transmission of math anxiety, Maloney et al. (2015) theorized that math-anxious parents can put their children at risk for developing math anxiety when they help their children with their homework. Studying families of children in first and second grade, Maloney et al. (2015) found that for higher-math-anxious parents, more frequent help with math homework lead to increased math anxiety by the end of the school year compared to children who received less homework help from their anxious parents or children who received help from nonanxious parents. However, see Jameson (2014), who did not find a parent-to-child math anxiety relation at a single time point.

The results of this study raise an interesting question: Why are higher-math-anxious parents leading children to develop math anxiety when they get more involved with their homework? One possibility is that these frequent interactions create opportunities for parents to express their beliefs about math (i.e., "Math is so confusing") or their own experiences around math (e.g., "I was always scared of math"), which normalizes a fear of math. Another possibility is that parents provide math problem-solving strategies that differ from those used by their teachers, which confuse children and leads to reduced math competency and higher math anxiety. Whatever the case, these results warrant parents to be mindful of the messages they may be conveying during their math homework interactions.

Although it is true that parents provide the genes and often the home environment (Wang et al., 2014), it is important to note that the Maloney et al. (2015) findings cannot easily be explained by a genetic account. Indeed, parents' math anxiety impacted their children's math anxiety and math learning, but only when those parents frequently helped their child with their math homework. When the parents did not help their child with their math homework, the parents' math anxiety was unrelated to their child's math anxiety or math learning. Although there is certainly a genetic component to math anxiety and math achievement, we do not know of any research suggesting a genetic component to one's propensity to help with homework.

In a related study, Berkowitz et al. (2015) investigated whether scaffolding parent–child interactions could improve math achievement. Participant families with early elementary school children received iPads with an app that structured interactions with math to increase input quality, and they were asked to use the app weekly during the upcoming school year. For children of higher-math-anxious parents, use of the app at least once per week lead to increased gains over the school year compared to children of math-anxious parents who used a reading app (control). These data indicate that through interactions that are structured to be conducive to learning, we can reduce the negative impact of parents' math anxiety on their homework help.

Negative math-related class experiences. Students build the majority of their math knowledge in the classroom, and oftentimes their first interactions with formal math begin with their teachers. Unfortunately, elementary teachers report particularly high levels of math anxiety (Battista, 1986; Bryant, 2009; Hembree, 1990), which potentially impacts how both teachers and students feel and perform in math. In fact, interviews and focus groups with math anxious adults (Chapline, 1980; Chavez & Widmer, 1982; Markovits, 2011) consistently link the development of math anxiety to negative experiences with elementary school teachers. A common theme across studies is that teachers' math anxiety contributes to children's math anxiety through their use of particular pedagogical practices (Allen, 2001; Chapline, 1980; Chavez & Widmer, 1982; Markovits, 2011), such as overemphasizing rote learning instead of more conceptual activities (Trujillo & Hadfield, 1999; Vinson, 2001) or presenting lessons in a more dogmatic manner (Ball, 1990). Research has shown that teachers who are low in math self-concept (i.e., those who believe themselves to be bad at math) report using textbook-based approaches and are less likely to rely on alternative teaching strategies than teachers high in math self-concept (Relich, 1996).

Another theme in this literature is that math anxiety makes it difficult for teachers to feel efficacious in their teaching responsibilities (Bursal & Paznokas, 2006; Gresham, 2008; Swars, Daane, & Geisen, 2006), which can lead to hostile reactions to students' own difficulties with math. For example, some adults report that they developed math anxiety because a teacher in their past responded angrily when they asked for help or seemed insensitive toward their struggle with math (Jackson & Leffingwell, 1999). There is a large body of narrative evidence supporting the idea that early negative experiences with teachers contribute to the development of math anxiety (Bulmahn & Young, 1982; Furner & Berman, 2005; Bryant, 2009; Kelly & Tomhave, 1985; Larson, 1983; M. Lazarus, 1974; Martinez, 1987; Ring, Pape, & Tittle, 2000; Sloan, Daane, & Giesen, 2002; Swetman, 1994; Tobias, 1981; Vinson, 2001). Here, a math-anxious teacher provides a particularly compelling account:

> One day I was teaching a concept and literally cried in front of my kids because I didn't get it either. When I expressed my disdain towards mathematics and my students witnessed my meltdown they immediately shut down and I lost them during math lessons for weeks afterwards. I know that seeing their teacher get frustrated with the math left a long lasting if not lifelong impression on them. (Gresham, 2017, p. 8)

In addition to this narrative evidence, a small number of quantitative studies have attempted to directly measure the relation between teachers' math anxiety and students' math outcomes. For example, Beilock et al. (2010) assessed math anxiety in first- and second-grade teachers as well as the math achievement and gender stereotype endorsement of the students in these teachers' classrooms. By the end of the school year, higher math anxiety in teachers was associated with both lower math achievement and higher stereotype endorsement (e.g., "Boys are good at math, and girls are good at reading") in their female students but not their male students. Further, female student's stereotype endorsement was found to mediate the relation between female teachers' math anxiety and their female student's math achievement. These data have often been used to support the claim that a teacher's math anxiety relates to students' own math anxiety. However, it is important to highlight that this study provided evidence for a relation between teacher math anxiety and students' ability beliefs (but not student math anxiety, which was not reported).

A similar finding was reported in a more recent study by Ramirez, Hooper, Kersting, Ferguson, and Yeager (2018), who found that higher levels of math anxiety among ninth-grade teachers (who are considered to be more specialized in math compared to elementary school teachers) was associated with lower math achievement among their students. The researchers hypothesized that this relation was mediated by students' perceptions of what their teacher believes about math. To assess this, the researchers asked students to rate how much they felt their teachers engaged in fixed-oriented teaching practices (i.e., My math teacher wants us to memorize things rather than use our thinking skills). As predicted, the researchers found that students' *perceptions* of their teacher's fixed mind-set beliefs explained the relation between teachers' math anxiety and student math achievement, above and beyond students' own mind-sets. In addition, students who had a higher-math-anxious teacher were more likely to perceive that their teacher employs fixed-oriented teaching practices. Such perceptions may lead students to believe that their teachers do not believe everyone is capable of learning math.

In addition to understanding the relation between math anxiety and teachers' mind-sets, it is also helpful to understand how math anxiety relates to teaching practices. Bush (1989) took a longitudinal assessment of pedagogical practices and student attitudes in fourth-, fifth-, and sixth-grade classrooms with teachers who had higher versus lower math anxiety. Bush found that teacher math anxiety was positively related to time spent on whole-class discussion and negatively related to number of questions asked by students. These results are consistent with the idea that teachers' attitudes impact their pedagogical practices, which in turn can impact their students' own attitudes, beliefs, and the manner in which they engage with math in the classroom.

Previous research suggests that math-anxious teachers also have lower expectations for student's math achievement (Mizala, Martinez, & Martinez, 2015). This is especially important to note, as students can pick up social cues from their teachers and make meaningful inferences about their potential for academic success (Ambady & Gray, 2002; Ambady & Rosenthal, 1993; J. E. Eccles, Adler, & Kaczala, 1982; Keller, 2001). Put differently, students are interpreting what they witness in the classroom and forming a story about the domain of math, their teachers, and themselves. We expand on this Interpretation Account next.

Interpretation Account

The various accounts explaining why individuals might develop math anxiety have been helpful in generating important programs of research. One shortcoming of these accounts, however, is that they do not explain why poor math abilities or negative learning experiences necessarily lead to math anxiety. After all, many students receive lower grades in math or learn under the same teachers as anxious students, and yet these students do not end up developing math anxiety. Conversely, we also find that there are many students who are both high achievers in math and highly math anxious (Lee, 2009). To reconcile this, we propose a novel Interpretation Account of how math anxiety develops and demonstrate how this new framework allows us to resolve some seemingly contradictory findings in the literature.

We draw from a large and disparate body of research to argue that students' development of math anxiety is largely determined by how they *interpret* (i.e., appraise) previous math experiences and outcomes (rather than the outcomes themselves). That is, math anxiety derives not just from a student's avoidance tendencies, reduced competency, or performance worries that shape the development of math anxiety but rather how individuals interpret their math-related experiences.

Our Interpretation Account stems from existing appraisal theory (Arnold, 1950; Barrett, 2006; R. S. Lazarus, 1991; Schacter & Singer, 1962) and an attitude-as-constructions view (Bem, 1972; Chaiken & Yates, 1985; Wilson, Lindsey, & Schooler, 2000), which argues that emotional outcomes and attitudes are based on the interpretation of events, physiological cues, personal behavior, and internal states. In fact, the basic tenet that changing maladaptive thoughts and beliefs shapes affective reactions is one of the pillars underlying the effectiveness of cognitive behavioral therapy for treating anxiety disorders (Butler, Chapman, Forman, & Beck, 2006; Deacon & Abramowitz, 2004; Olatunji, Cisler, & Deacon, 2010). More recently we have seen an application of appraisal theory toward the interpretation of more commonplace stress (Blascovich & Mendes, 2010; Jamieson, Mendes, & Nock, 2013), health (Idler & Kasl, 1991; Kaplan & Camacho, 1983), and broad emotion regulation (Kross & Ayduk, 2011; Ochsner & Gross, 2008). Considering the long-standing tradition of the application of appraisal theory to the interpretation of stress and emotions, it is surprising that this perspective has not been extensively discussed in the math anxiety literature before now.

Evidence for an interpretation account. We begin our review of evidence supporting our Interpretation Account by reviewing research by Meece et al. (1990). This study investigated how children's interpretation of math skills leads to the development of math anxiety in a sample of students from seventh through ninth grade. Meece et al. collected the math grades of students during middle school and assessed whether students' grades during their 1st year in the study related to their own perceived math ability, how important math is to them, and their expectations for success in math next year. The researchers then measured how much math anxiety students reported during the 2nd year of the study.

Their results showed that students' perceptions of their math ability at Year 1 (but not their actual math grade in Year 1) had a direct effect on Year 2 math anxiety. Students' perceived ability at Year 1 also indirectly predicted Year 2 math anxiety through a change in Year 2 success expectations and Year 2 ratings of how important math is. Thus, it seems that the *interpretation* that students choose to take about their performance in math, and not their actual prior achievement in math classes, is the strongest predictor of their subsequent math anxiety. Similar findings have been found in the domain of health outcomes;

for example, Idler and Benyamini (1997) conducted a meta-analysis of 27 studies and found that how individuals perceived their health was a significant indicator of mortality, oftentimes even more predictive than actual health outcomes (see also Kaplan & Camacho, 1983).

The results of Meece et al. (1990) help explain other research findings as well. For instance, we previously summarized several studies (Gunderson et al., 2017; Ma & Xu, 2004; Ramirez, Fries, et al., 2017) showing that early achievement has a much stronger effect on later anxiety, relative to the effect that early anxiety has on later achievement. One reason that early achievement is a strong predictor of later math anxiety is that students may view their math performance as a means of assessing their ability to be successful in math, which subsequently can create a fear of math (Meece et al., 1990). Students who apply maladaptive appraisals or attribute poor math grades to ability may be more likely to develop math anxiety, as opposed to those who attribute it to a lack of effort or who acknowledge that math is a difficult subject for most students and mistakes are necessary for learning.

Research examining the relation between self-concept and math anxiety provides additional support for our Interpretation Account. Work by Jameson (2014) found that math self-concept in second-grade children was a stronger predictor of math anxiety than parent math anxiety, child gender, and home math activity (see also Ferla, Valcke, & Cai, 2009; Lee, 2009). Work from Ahmed, Minnaert, Kuyper, and van der Werf (2012) attempted to answer an important follow-up question: Which comes first, poor self-concept of ability or math anxiety? They took measures of math anxiety and math self-concept at different time points during the seventh grade, and a cross-lagged panel analysis revealed a bidirectional relation between math self-concept and math anxiety. However, the effect of lower self-concept on math anxiety was twice as strong as the effect of math anxiety on self-concept. The authors suggest that the path from math self-concept to math anxiety may be more powerful because students can develop "dysfunctional self-schemas" of themselves that negatively affected the appraisal of their own ability to do well in math (Ahmed et al., 2012).

Jain and Dowson (2009) investigated how self-regulation and self-efficacy predict math anxiety in a diverse sample of eighth-grade students. Results showed that lower self-regulatory processes in students led to lower perception of personal competence, which led to an increase in math anxiety. The authors suggest that students with a lower perception of personal competence may have difficulty shrugging off previous difficulties with math (e.g., "I didn't do so well in my last math class. I am just not comfortable around math"), which predisposes them to fear subsequent situations that involve math. Thus, giving students' adaptive appraisals via high self-efficacy, math self-concept, or an effort-based view of math intelligence, may be an important factor in helping to redirect students away from taking on a maladaptive interpretation of their math experiences.

If our Interpretation Account is correct, then students who naturally redirect their appraisal in a more positive-adaptive way could overcome their negative responses associated with math anxiety. Consistent with this idea, Lyons and Beilock (2012a) posited that college students who are high-math-anxious but also high performing may be reappraising, or reinterpreting, their arousal while in math-learning and math-testing situations. This hypothesis was supported by a neuroimaging study in which Lyons and Beilock (2012a) had higher- and lower-math-anxious undergraduate college students perform a math task block and a verbal task block that was matched in difficulty. Before each problem set, students saw a cue that indicated whether the next set of trials was going to be a math set or a word set. Showing the cue in advance allowed the researchers to separate the neural activity associated with the anticipation of doing a math problem from the neural activity associated with actually doing math calculations.

Lyons and Beilock (2012a) found that during the time between being cued for an upcoming math trial and actually completing the problems, higher-performing math-anxious undergraduates showed increased activation of a frontoparietal network that is known to be involved in the control of negative emotions. Lower-math-anxious students did not show this increased activation. Not surprising, results showed that the more activation the higher-math-anxious individuals showed in this frontoparietal network before the math task, the better they performed. The authors suggest that successful higher-math-anxious participants may be recruiting these frontoparietal regions to engage in reappraisal before they begin the math task.

Appraisal processing that takes places before, during, and after a student does math may be key to explaining what causes math anxiety, as well who is vulnerable to its effects. But what factors affect a student's ability to successfully reappraise? The answer may lie within a student's motivation. In a 2015 study, Wang et al. asked whether intrinsic math motivation among adolescents and adults moderated the relation between math anxiety and math achievement. Wang et al. (2015) found that adolescents with lower intrinsic math motivation showed the well-documented negative relation between math anxiety and math performance. Yet, for adolescent students with higher levels of math motivation, higher levels of math anxiety were initially associated with better performance, but as anxiety increased, performance began to drop off at the highest levels of math anxiety (in essence, they demonstrated an inverted-U function). These results suggest that students with low intrinsic motivation may not use positive appraisal processes to regulate their emotional experience, and they instead succumb to the negative thoughts and worries that disrupt working memory. For those with high intrinsic math motivation, however, a moderate amount of math anxiety was associated with optimal performance, perhaps because these students felt a drive to do well in math despite their anxious response.

The pattern of results outlined so far suggest that providing math-anxious students with appropriate appraisal cues and meaning-making frameworks may help them overcome their otherwise maladaptive appraisal of disfluent math experiences. In the absence of high motivation for positively appraising a situation, it may be quite difficult for students to take on a more adaptive interpretation of their anxiety around math. This is because physiological experiences such as heightened arousal and sweaty palms are commonly understood as sign of probable failure, making it difficult for math anxious students to reappraise their math experience.

A clear example of this notion comes from Mattarella-Micke et al. (2011), who theorized that for students *low* in math anxiety, a heightened physiological reaction (i.e., sweaty palms, racing heart) could be interpreted as a cue that they are in a challenging situation, which might enhance performance (see Jamieson, Nock, & Mendes's, 2012, work on challenge vs. threat). In contrast, for students who are *high* in math anxiety, a heightened physiological reaction may be interpreted as math-related distress, which could lead to worries and underperformance. Data from Mattarella-Micke and colleagues showed that an increase in the concentration of cortisol (a marker of physiological arousal) was positively associated with math performance for lower-math-anxious students. In contrast, an increase in the concentration of cortisol was negatively associated with math performance for those higher in math anxiety. That is, individuals' attitudes toward math are not just a product of their interpretation of past events but also their interpretation of physiological responses in the moment. Research by Mattarella-Micke and colleagues suggests that, just as reappraisal of past math experiences can affect the development of math anxiety, moment-to-moment appraisals of physiological cues can modulate the extent to which math anxiety impacts performance.

A major premise of our Interpretation Account is that students play an active role in creating meaning of their educational experiences, and one of the ways they do this is by seeing the world through an interpretative lens that is shaped by an internal narrative. The notion that students apply ongoing narratives toward better understanding themselves and past educational experiences resonates with several theories implicating a "storytelling self" (Baumeister & Newman, 1994; Wilson, 2011) or "narrative identity" (McAdams, 2001; McLean, Pasupathi, & Pals, 2007). There is even a growing body of work on narrative understandings of math development and "story" experiences around math (I. Carter, 1993; K. Carter & Stoehr, 2011).

Students engage with internal narratives to gain a sense of stability, unity, and purpose, as well as to maintain an overarching narrative of the self's adequacy (i.e., "I am generally a good student, but math is something that just freaks me out"). Unfortunately, some students impose maladaptive interpretative narratives toward their disfluent math experiences, which can create a self-fulling prophecy. Maladaptive interpretations can redirect students to view both past experiences (Woike & Polo, 2001) and ongoing and future events (Sherman & Cohen, 2006) in a manner that is consistent with the narrative they choose to tell. This would help to explain why math anxiety is often associated with ruminations (Ashcraft & Kirk, 2001).

This is not to say that the nature of the student's interpretation is unaffected by external factors. When viewing some of the previously discussed studies from an interpretation account, it is clear that the appraisals that students adopt may be heavily shaped by their social environments. Some external influences that shape appraisals include the following:

- Existing cultural stereotypes (i.e., "Women hate math, so I must hate math as well"; Bieg et al., 2015).
- Societal beliefs around disfluent learning (i.e., "If you are having trouble learning something, then you are probably not going to perform very well"; Benjamin, Bjork, & Schwartz, 1998; Koriat & Bjork, 2006; Stigler & Hiebert, 2004).
- Social interactions in the home ("My parents always help me with math homework because I am not very comfortable doing it on my own"; Maloney et al., 2015).
- Social interactions in class ("My teacher gets really stressed out teaching math"; Beilock et al., 2010).
- Teaching pedagogy ("My teacher doesn't ask us questions or encourage us to think deeply about math because he/she believes that not everyone can be good at math"; Ramirez et al., 2018).
- Lay beliefs about the meaning of heightened physiological arousal (i.e., "My heart is beating fast, I must be really nervous"; Jamieson et al., 2012).

To expand on one example, we return to the study by Maloney et al. (2015) that showed that higher frequency of homework help among math-anxious parents was associated with reduced math growth as well as heightened math anxiety across the school year. One account for this result is that parents are confusing students with alternative problem-solving strategies. However, another possibility is that children interpret the frequent help from parents as a sign that perhaps their parents think they are bad at math or that math is something to fear. Previous work finds that parents who provide more uninvited help can lead children to adopt lower perceptions of their math ability (Bhanot &

Jovanovic, 2005; Pomerantz & Ruble, 1998), which is predictive of higher math anxiety.

In summary, we have presented a novel Interpretation Account for why students may develop math anxiety. This account argues that maladaptive interpretations of ongoing and previous math experiences are a key factor in determining who develops math anxiety and whose performance suffers as a function of math anxiety. Our Interpretation Account provides a retelling of previous research and helps synthesize disparate research findings. Viewing the math anxiety literature from this Interpretation Account may provide us with important clues about the additional factors that moderate the development, growth, and impact of math anxiety, as well as ways to remediate math anxiety once it has already taken hold—issues we return to later in the article.

WHO IS IMPACTED BY MATH ANXIETY?

Up until now, we have primarily discussed math-anxious students in terms of general trends. It is clear, however, that there are various populations who are particularly vulnerable to the effects of math anxiety. There also exist several demographic factors that moderate the magnitude of the math anxiety–achievement relation, which we discuss in greater detail next.

Math Anxiety and Gender

Many studies have reported higher levels of math anxiety for women than for men (e.g., Ashcraft & Faust, 1994; Baloglu & Kocak, 2006; Bernstein, 1992; Betz, 1978; Else-Quest, Hyde, & Linn, 2010; Hembree, 1990; Hopko, Mahadevan, Bare, & Hunt, 2003; Hopko et al., 2003; Ma & Cartwright, 2003; Wigfield & Meece, 1988). Other studies, however, have failed to find such a gender difference (e.g., S. E. Cooper & Robinson, 1991; Hackett, 1985). Nonetheless, when examining math anxiety on a large scale, it does appear that there are gender differences. One study by Stoet, Bailey, Moore, and Geary (2016) measured math anxiety among 761,655 high school students across 68 nations who participated in PISA. The researchers found that female participants reported more math anxiety than male participants overall, and the math anxiety and gender gap widened as the country increased in economic development.

To date, there has been no definitive answer to the question of why women are more likely to be more math anxious than men. However, a few hypotheses have been put forth. For example, Maloney et al. (2011) demonstrated that the gender difference in math anxiety is mediated by spatial-processing ability. In other words, women may be more math anxious than men, on average, because women are worse at spatial processing than men (and spatial processing is an integral part of mathematics; e.g., Cheng & Mix, 2014). That said, Ashcraft and colleagues speculated that the gender difference in math anxiety may occur because women are more comfortable reporting anxiety (e.g., Ashcraft, 2002). Alternatively, Beilock, Rydell, and McConnell (2007) suggested that the gender difference is the result of the social stereotype that women are worse at math compared to men. Additional evidence supporting this social stereotype account comes from Goetz et al. (2013), who asked male and female students from Grades 5 through 11 to report their trait-level math anxiety using a questionnaire outside of class. They found that girls do, in fact, self-report higher math anxiety than boys. However, when students were probed about their real-time math anxiety directly before and during a math exam, girls did not report more anxiety symptoms than boys. Follow-up research revealed that this discrepancy between trait and state math anxiety was larger among students with a low math self-concept and those who endorsed traditional gender stereotype of math traditionally being a male dominant field (Bieg et al., 2015). In line with our Interpretation Account, these results suggest that stereotyped beliefs about how women should feel about math (rather than actual ability) may explain the observed gender difference in math anxiety.

MATH ANXIETY IN EARLY DEVELOPMENT

The majority of math anxiety research has been conducted among college student populations, but recently there has been a strong interest in studying math anxiety at the elementary school level. This shift has been dramatic, as researchers believed for a long time that the onset of math anxiety began around sixth grade, despite the qualitative reports from adults that the cause of their math anxiety had been earlier math experiences (Jackson & Leffingwell, 1999). Part of the lack of interest in studying math anxiety early in development could have stemmed from several studies reporting no consistent relation between math anxiety and performance in elementary school (Dowker, Bennett, & Smith, 2012; Krinzinger, Kaufmann, & Willmes, 2009), which may have led some researchers to question whether young children experienced math anxiety or if they were adequately capable of describing how they felt. For some time, there has been an interesting discussion around whether children have the cognitive sophistication to adequately report their feelings about math anxiety (Ashcraft & Krause, 2007; Ganley & McGraw, 2016; Vukovic, Kieffer, et al., 2013). Despite some of the aforementioned misconceptions, researchers have now amassed a growing body of work focused on studying math anxiety at a very young age. A review of this work reveals the following:

1. Young children are, in fact, capable of understanding and reporting their feelings of anxiety toward math.

Several studies conducted pilot tests and cognitive interviews in which children demonstrate a good understanding of what it means to be nervous, anxious, or tense about math (Ganley & McGraw, 2016; Ramirez et al., 2013; Vukovic, Kieffer, et al., 2013).

2. Even children at the very start of formal schooling report experiencing math anxiety. A number of studies have reported reliable evidence that first graders experience math-specific anxiety (Aarnos & Perkkilä, 2012; Ramirez et al., 2016; Ramirez et al., 2013; Thomas & Dowker, 2000).
3. Higher math anxiety is inversely linked with lower performance on various math performance indices, such as achievement test scores from school records (Gierl & Bisanz, 1995), standardized achievement batteries (Jameson, 2014; Ramirez et al., 2016; Ramirez et al., 2013; Wu, Barth, Amin, Malcarne, & Menon, 2012), tasks examining whole-number computation skills and math concepts (Harari, Vukovic, & Bailey, 2013), as well as mathematical applications (Vukovic, Kieffer, et al., 2013).
4. WM is an important construct underlying the relation between math anxiety and performance. Some studies have focused on the mediating role of WM-related brain processes (Young et al., 2012), whereas others examined WM as a moderator (Ramirez et al., 2016; Vukovic, Kieffer, et al., 2013) or investigated the WM demands of the specific task at hand (Ramirez et al., 2013; Wu et al., 2012).

This more recent interest in studying math anxiety in younger populations has led to a number of instruments for assessing individual differences in math anxiety (for an excellent review of the existing scales for measuring math anxiety, see Eden, Heine, & Jacobs, 2013, and Ganley & McGraw, 2016). Some of these instruments ask children to respond by selecting a series of cartoon faces (Jameson, 2013; Krinzinger et al., 2009; Ramirez et al., 2013; Thomas & Dowker, 2000; Wu et al., 2017), whereas others require children to select from a short list of verbal responses (Ganley & McGraw, 2016; Harari et al., 2013; Vukovic, Kieffer, et al., 2013).

Math Anxiety Across Age

Although interest in early math anxiety has recently peaked, there has been a continuous interest in understanding the developmental trajectory of math anxiety for some time. Understanding the trajectory of math anxiety has the potential to address whether math anxiety builds across an accumulation of negative schooling experiences (Ashcraft & Faust, 1994) or is instead concentrated across particular schooling periods (e.g., adolescence), which might highlight important points for remediation. Unfortunately, as of now we are unaware of a well-powered study that has examined changes in math anxiety in K-12. However, in this next section we attempt to approximate the developmental trajectory of math anxiety by reviewing studies that have largely taken a cross-sectional approach to examining trends of math anxiety prevalence.

One of the most extensive studies investigating the trajectory of math anxiety came from Hembree's (1990) meta-analysis, which looked at math anxiety from sixth grade to college. This meta-analysis summarized dozens of cross-sectional studies and reported that math anxiety is least prevalent in sixth grade and peaks at around ninth grade before leveling off in subsequent years. Wigfield and Meece (1988) found a similar pattern of results in their study examining math anxiety from middle school to high school. Wigfield and Meece found that math anxiety was the lowest in sixth grade, highest in ninth grade, and leveled off in later years. From these results, the beginning of high school appears to be a particularly important educational period for children's development of math anxiety.

Other reports, however, have found a different pattern. Suinn and Edwards (1982) examined math anxiety scores among children from seventh to 12th grade and found that students reported the highest median math anxiety scores during seventh grade and then showed a downward trend in the amount of math anxiety reported from eighth through 12th grade. Other studies that have examined math anxiety in late elementary through middle school have found that from fourth to eighth grade, the math anxiety trend follows an inverted U-shape with a peak around sixth grade (Chiu & Henry, 1990). Gierl and Bisanz (1995) also reported a peak in math test anxiety during sixth grade.

At the early elementary school level, we typically find a downward trend: Several studies examining children's math anxiety between first and third grade (Krinzinger et al., 2009; Ramirez et al., 2016; Ramirez et al., 2013; Vukovic, Kieffer, et al., 2013) report a reduction in average math anxiety across school year cohort observed. However, M. M. Jameson (personal communication, September 13, 2017) reported a peak in third grade (rather than a downward trend) in her study measuring math anxiety from first to fourth grade (Jameson, 2013). Although these different results may suggest that math anxiety fluctuates from year to year, there exist several studies that find *no* meaningful difference between years observed. Math anxiety studies examining children in Grades 4–6 (Suinn, Taylor, & Edwards, 1988), Grades 4 and 5 (Yüksel-Şahin, 2008), Grades 3 and 5 (Dowker et al., 2012), and Grades 1–3 (Ganley & McGraw, 2016; Wu et al., 2012; Young et al., 2012) report no differences in that math anxiety across these school grades.

In sum, there is no clear trend across various cross-sectional studies examining math anxiety across different age groups. It is important to note, however, that due to the recent reforms in math education, current trends may be very different from the findings reported by older studies.

In addition, although many of the aforementioned studies are cross-sectional, they do not support a view that math anxiety snowballs across time. That is, if math anxiety were a culmination of negative experiences that became exacerbated over time, we would expect children in higher grades to have more math anxiety. However, that is not what we generally find.

HOW CAN WE MITIGATE MATH ANXIETY?

Thus far, we have identified different frameworks for explaining the development and impact of math anxiety. We have also reviewed findings from studies that collectively suggest that math anxiety is a multifaceted construct that is created, influenced, and sustained by a variety of individual-difference factors. As such, the effort to combat math anxiety has also been diverse in its approach. Next we review some of the most successful interventions that reduce math anxiety and/or reduce the negative impact of math anxiety on achievement. We also highlight areas that are in current need of additional interventions.

Math Skill and Exposure Interventions

According to the Reduced Competency Account, interventions that aim to improve students' math skills may also be effective at reducing math anxiety. Supekar, Iuculano, Chen, and Menon, (2015) demonstrated that an intensive 8-week, one-on-one cognitive tutoring program reduces math anxiety in children. Similar to phobia interventions, the researchers found that exposure to math could not only improve math skills but also reduce anxiety through desensitization. Before the intervention, children participated in fMRI scans, which found that when doing math, higher-math-anxious students had aberrant neural responses and connectivity in emotion-related circuits centered in the amygdala. However, after the 8-week intervention, follow-up fMRI scans showed that these aberrant neurological responses disappeared, and there were no differences in brain activation between higher- and lower-math-anxious children. Crucially, Supekar et al. found that children with greater tutoring-induced decreases in amygdala reactivity had larger reductions in math anxiety. The results of this study suggest that improving math skills is important to reducing math anxiety and desensitizing individuals to math.

The Avoidance framework under the Reduced Competency Account states that avoidance tendencies may be responsible for the deficits in development (and explains why increased exposure is an effective solution). If this is the case, then there are a number of interesting interventions that could be conducted to increase engagement with math. For instance, parents who play number-rich board games at home may reap benefits beyond improving children's numerical representation (Laski & Siegler, 2014; Ramani & Siegler, 2008; Siegler & Ramani, 2008, 2009; Whyte & Bull, 2008). Use of number-rich board games may help children to connect math with their everyday lives (Petersen & Hyde, 2017), model a positive disposition around math in the home, and desensitize heightened anxiety around math. Although such informal math activities have been found to increase math skills and interest in math, as far as we are aware, research linking these activities to math anxiety has yet to be conducted. The previously discussed Berkowitz et al. (2015) parent study with iPads provides one conceptual example for how math activities in the home can create better outcomes by scaffolding parent–child interactions around math.

Interpretation Interventions

Our Interpretation Account indicates the importance of appraisal processes in shaping not only who develops math anxiety but also whether math-anxious students falter or thrive during demanding math situations. Games and interactive platforms might encourage students to engage with math more and appraise math as enjoyable. Students may, however, be unwilling to persist in math if they interpret struggles as a product of their own inability rather than a natural part of learning. It is important that students understand that math is not always fun and that there is a lot to gain from productively struggling and engaging in sense-making processes around math (Hiebert & Grouws, 2007). Indeed, one of the most promising avenues of remediation is work suggesting that, rather than suppressing worries or avoiding math, it can be effective to encourage individuals to reappraise their math anxious reaction or embrace the view that disfluent learning can be useful.

Interpretation of physiological arousal. When students are placed in stressful academic situations, many overcome their affective reaction by viewing the situation as a challenge that they can overcome rather than as a threat they should avoid. Such an account is well described by the biopsychosocial model of challenge and threat (Blascovich & Mendes, 2010), which argues that situational demands can be evaluated as threatening when individuals appraise that they do not have the personal resources (e.g., self-efficacy, motivation, intelligence, knowledge, social support) to properly address those demands. In contrast, individuals who appraise that they have personal resources to meet the situational demands are more likely to view those demands as a challenge, which facilitates performance.

Recently, research on reappraisal has been extended to the domain of math anxiety. Jamieson, Peters, Greenwood, and Altose (2016) looked at the benefits of reappraisal among community college students enrolled in a remedial math course. In their experiment, one group of participants read about how heightened physiological arousal was optimal for performance (appraisal condition). Another group of participants were given standard information about the benefits of simply ignoring stress during an exam (control condition). When it came time for their class exams, students in the appraisal condition showed greater improvement across exams and reported less math anxiety compared to control participants.

Another avenue of interventions involves helping students to reduce or regulate worries that often guide their negative appraisals (Ashcraft & Kirk, 2001). Park, Ramirez, and Beilock (2014) employed an expressive writing technique aimed at reducing the number of intrusive thoughts of math-anxious individuals in order to improve math performance. Specifically, Park et al. had higher- and lower-math-anxious adults complete tests of math ability before and after engaging in an expressive writing exercise, in which they wrote openly regarding how they felt about an upcoming math test. After only one session of expressive writing, the higher-math-anxious participants experienced a boost in their math performance relative to their pretest scores, narrowing the performance gap between them and their lower-math-anxious peers. These results may have occurred because students who confronted their negative thoughts and worries gained insights that are not experienced by students who suppressed or avoided their own concerns. This finding is consistent with some of the most successful treatments for clinical anxiety disorders (Becker, Darius, & Schaumberg, 2007; Foa et al., 2005). In fact, we find from previous meta-analytic results that systematic desensitization as well as cognitive restructuring are among the most efficacious treatments for math anxiety (Hembree, 1990).

Narrative and mind-set interventions. The primary benefits of reappraisal and expressive writing interventions may lie in giving students an opportunity to make sense of their ongoing experience, allowing them to edit their ongoing narrative and the resulting appraisal processes (Baumeister & Newman, 1994; McAdams, 2001; McLean et al., 2007; Wilson, 2011). However, rather than temporarily change how students appraise the situation, we think a more useful framework for reducing math anxiety may be to help students adopt a failure-as-enhancing mind-set rather than a failure-as-debilitating mind-set.

We highlighted earlier that students' narratives and appraisal processes are likely shaped by their social environment. In a classic study, Dweck (1975) also provided evidence that reappraisal of failure as efficacious can help children with learned helplessness to perform better in math. In her study, students who showed signs of learned helplessness were put either on a success track or failure-reappraisal track. In the success track, any failure that students faced during their math performance was either ignored or glossed over. In the failure-reappraisal condition, students were forced to fail and informed that it was because they did not put in enough effort. By the end of the experimental training, students in the failure-reappraisal condition not only stopped showing declines in performance after failures but also began to show increases in performance overall. Dweck reasoned that students now saw failure as a cue to "escalate effort," and a subset of children in this condition even reportedly began to verbalize their newly trained attribution after they failed (Dweck, 1975).

Interventions designed to change individuals' mind-set (Blackwell, Trzesniewski, & Dweck, 2007) and give students a distanced perspective to better appraise stressful situations (Kross & Ayduk, 2011; Ochsner & Gross, 2008) can be long-lasting. To build upon this, subsequent research in this field should examine how to create lasting change in students' views of disfluent math learning and the personal math narratives that they carry with them. Specifically, it would be helpful for researchers to investigate whether (a) a failure-as-enhancing mind-set and (b) more effort to reappraise failure can have similar long-term benefits in the domain of math anxiety. Our intuition is that such interventions would work better if they are accompanied by a shift in the mind-set beliefs of the organization and culture in which children learn math (i.e., within classes and the home; Hooper, Yeager, Haimovitz, Wright, & Murphy, 2016; Murphy & Dweck, 2010).

Educators must show, through their everyday interactions with students, that math material can be learned by everyone and that failure is normal and perhaps even optimal for improving. An example of this idea applied in a classroom can be found in the research of Lin-Siegler, Ahn, Chen, Fang, and Luna-Lucero (2016). In their study, they hypothesized that students who learn about the struggles of famous scientists might feel more connected to the scientific content they were learning, perhaps because these narratives helped to normalize failure. This, they reasoned, would help students to learn more and produce higher grades. Their results supported the hypothesis: Students who learned about the struggles and failures of famous scientists (as opposed to learning about the scientists' achievements) felt more connected to the content and later showed higher grades. Furthermore, this effect was especially pronounced in low-performing students. The authors suggested that because a critical part of science learning is working through failure, presenting a realistic picture of struggle may have inspired students to persist in the face of failure.

Similarly, Wilson and Linville (1985) reasoned that many 1st-year college students view academic struggles as possible evidence that they do not fit in or have the intelligence to succeed. To test how this mind-set could be improved, Wilson and Linville designed an intervention in which students either watched videos about what to expect during college or received no information. In the videos shown to the intervention group, current college students explained that it is common to struggle during the 1st year of college and that after an adjustment period, things would get better. The students who experienced this short intervention had higher course grades and retention rates relative to the control group, suggesting that the messaging may have helped redirect them toward a more adaptive interpretation, or "story re-editing," of the struggles they suffered during their 1st year of college (Wilson, 2011). That is, being introduced to struggle and failure as a normal process allows students to use a more flexible appraisal process when they experience failure themselves.

In summary, there have been many promising studies for the treatment of math anxiety, yet there is much more than can be done. We view the Interpretation Account framework as an important direction for the next generation of math anxiety intervention research.

WHERE DO WE GO FROM HERE?

Research on math anxiety has made great progress, leveraging findings from the fields of education, psychology, and neuroscience to garner a better understanding of its causes, consequences, and potential remediation. However, there are many areas in need of research effort, which we describe next. It is our hope that these areas will be addressed in future work to improve our understanding math anxiety.

Flexibility

One issue that should receive greater attention is the role of math anxiety in the development of flexible strategic thinking and conceptual understanding. Much of the earlier work on math anxiety has focused on using standardized achievement batteries to examine how math anxiety affects students' general memory retrieval and fluency in math. Even today, a significant portion of the literature is focused on students' speed and accuracy at solving basic arithmetic problems. However, the literature on math anxiety would be greatly enhanced if it expanded to include the study of flexibility. Math flexibility describes the ability to flexibly shift between various strategies and reasoning when doing math, which is considered a critical skill for solving new and unfamiliar math problems (National Research Council & Mathematics Learning Study Committee, 2001). Math flexibility has been shown to improve both procedural knowledge and conceptual knowledge (Star et al., 2015)—expertise that is necessary to learn and perform math successfully. Furthermore, flexibility in math is arguably one of the defining characteristics of the mathematically gifted (Mann, 2006).

By repeatedly depending on only a few learned strategies, inflexibility impedes more advanced skill development, which can in turn influence conceptual understanding (De Jong & Ferguson-Hessler, 1996; Glaser, 1991). Unfortunately, there is not enough research to draw any meaningful conclusions about how math anxiety might affect a student's ability to learn and deploy a variety of problem-solving strategies (see Imbo & Vandierendonck, 2007; Ramirez et al., 2016). However, we encourage researchers to look at research in the domain of stereotype threat, which is beginning to develop a rich body of knowledge on the ways in which anxiety affects students' deployment of prepotent responses (Jamieson & Harkins, 2007).

Retention

Another important outcome that has received little attention is the role of math anxiety on retention of mathematics material across time. Bahrick and Hall (1991) conducted one of the most extensive investigations into the factors that predict mathematics retention. Their investigation found that both subsequent course taking and curriculum and schedule of instruction were much stronger predictors of knowledge retention than individual-difference variables such as aptitude and school grades. Yet math anxiety has, up to this point, remained relatively uninvestigated as potential predictor of math knowledge retention. In one qualitative study, a math anxious adult reflects the following:

> During middle and high school, I know my attitude towards math was 100% affected by my low test scores. I began to build a wall towards math and it was, and it still is sometimes tough for me to open up and soak up information. (Stoehr, 2017, p. 75)

It is common to hear students report that they forgot everything they learned in math courses soon after finishing. Considering the aversive nature of math courses for math-anxious students and the role that avoidance plays in math anxiety, one issue worth addressing is how defensive reactions modulate the retention of math content. Experiences like the one outlined in the preceding quote have recently led some researchers to wonder whether stress and anxiety around math might encourage students to engage in defensive reactions that intentionally suppress (i.e., forget) memories for the math they learn—a phenomenon known as *motivated forgetting*.

In a field study on motivated forgetting, Ramirez, McDonough, and Jin (2017) asked whether stressful course experiences around math might lead to a higher rate of forgetting once students completed a college course on multivariate calculus. To address this question, they measured individual differences in ongoing stress once a week while students were taking multivariate calculus. Two weeks after the course was completed, students were asked to complete a surprise follow-up exam on the same content covered on their original final exam.

Ramirez, McDonough, et al. (2017) found that higher ongoing stress did not relate to how students performed on the final exam of the class. However, they did find that students who had reported higher ongoing stress showed a steeper rate of forgetting, but only for students who reported a strong math identity. A similar finding has also been observed among young children (Ramirez, 2017). Students whose identity is strongly tied to math may have appraised ongoing course stress as a threat to their identity and engaged in motivated forgetting to protect the personal image they wanted to maintain. Put differently, students may have been motivated to edit out the parts of their life that did not cohere with the story that they wanted to tell about being "good at math." In future work, it is important to address whether a similar process could also be happening in math-anxious students, such that they dismiss positive math experiences once they have adopted a particularly negative narrative about their abilities in math.

DIVERSE POPULATIONS

Although the majority of math anxiety research conducted in higher education has focused on 4-year university students, there is much to gain from focusing more on math anxiety in community college students. Community colleges typically serve a greater percentage of low-income, nontraditional, and minority students than other 4-year universities (Provasnik & Planty, 2008), and because enrollment is less competitive, community colleges also serve students with more variability in math skill. In particular, community colleges traditionally offer more developmental courses than 4-year universities. Students in these developmental math courses have shown poor math skills (Givvin, Stigler, & Thompson, 2011; Stigler, Givvin, & Thompson, 2010), which may explain why community college students overall report higher estimates of math anxiety than students at a 4-year university (Yeager, as cited in Chang & Beilock, 2016). In one recent meta-analysis, Sprute and Beilock (2016) found that developmental community college students show more variability in math anxiety than 4-year university students and that almost half of these students experienced moderate to high math anxiety. This finding highlights developmental community college students as one of the highest concentrations of math-anxious students in all of education—an optimal subpopulation for study.

As much as the field would benefit from studying math-anxious students who do not identify strongly with math, the opposite side of the spectrum is also an important population of study—students who are math anxious but also have strong math identity and math motivation. A large majority of research thus far has focused on a general sample of college students and assumed that math anxious students have low motivation. However, as we have reviewed throughout this article, math anxious students sometimes show high achievement and can be math motivated. Work previously mentioned in motivated forgetting, for example, highlights the necessity to investigate the role of math anxiety among individuals who are highly identified with the domain of math, show high math motivation, or are pursuing a career with heavy math requirements.

CONCLUSIONS

Math anxiety is a phenomenon with a complex etiology and a host of negative consequences. It impacts all ages, from young children to older adults, and worldwide it is related to decreased math achievement and negative attitudes about math. Here, we have aimed to provide an encompassing review of the literature to date, drawing on findings from education, psychology, and neuroscience to highlight the causes, consequences, and promising interventions of math anxiety. Along with examining the existing frameworks that work to explain the causes of math anxiety and its link to poor performance, we also propose a new Interpretation Account framework that demonstrates how appraisal can strongly influence anxiety and performance. By proposing this new framework in relation to math anxiety, and by outlining a number of central unresolved questions, we hope to help guide future research in this important area.

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