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# Mathematics anxiety and stereotype threat: shared mechanisms, negative consequences and promising interventions

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Proficiency in mathematics is a major advantage in industrialised nations. Here we discuss several emotional impediments to mathematics achievement, namely mathematics anxiety and stereotype threat. Synthesising findings from empirical studies in the fields of cognitive, social, and educational psychology, as well as neuroscience, we discuss some of the ways that affective factors can negatively impact mathematical performance and lead to avoidance of mathematics and mathematics-related fields. We bring together the mathematics anxiety and stereotype threat literatures by suggesting that these two phenomena share a common underlying mechanism, which causes disturbance in mathematics performance. We end by suggesting a number of potential interventions aimed at reducing the negative consequences of anxiety and stereotype threat on mathematics performance – interventions fueled by an understanding of the cognitive and neural mechanisms by which mathematics anxiety and stereotype threat work to impact performance.

**Keywords:** mathematics anxiety; stereotype threat; mathematics achievement

> Math. I hate math. It makes me feel all wiggly inside. During the [high stakes test] last year, I thought I was going to throw up when we did the math part. I didn't, but I always feel that way even when we just line up for math class.
> (10 year old girl when asked to write about her least favourite subject)

The above quote, taken from a 10 year old girl's journal, illustrates a common experience in the classroom: anxiety. Most students want to perform well in academic settings, but for many, including the student quoted above, feelings of anxiety can negatively impact their performance. In today's education system, students (and teachers) are constantly being evaluated. Students are often bombarded with assessments: weekly assessments, unit tests, federally mandated high stakes testing, and even practice tests for the high stakes tests. But what happens when these measures don't accurately capture a students' knowledge or skill? The above quote begs this question: would this student have performed differently on the high stakes test that she described if she had not felt "wiggly" or sick to her stomach?

The effects of anxiety are not limited to physical symptoms, such as those described above. Indeed, anxiety can impact student performance on in-class assessments and standardised tests as well as decisions regarding which career paths to pursue (e.g., Hembree, 1990). In the present review, we summarise psychological and neuroscience research highlighting, specifically, the negative effects of anxiety on mathematics performance. We also talk about a related negative performance

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phenomenon in mathematics, namely stereotype threat, whereby people underperform relative to their ability merely because they are aware of a negative stereotype about how they should perform – e.g., a female student aware of the stereotype that "boys are better than girls at mathematics". We discuss how these two phenomena, despite having different etiologies, may impact performance via the same mechanism, and then we provide evidence that, for many students, scores on high-stakes tests are often depressed as a function of the test-taker's anxiety and feelings of stereotype threat. Importantly, we also demonstrate how such negative affective factors can be systematically and objectively studied in laboratory and classroom settings, thus setting the stage for the development of interventions designed to alleviate them. We end by highlighting tools that will hopefully prove to be effective means of reducing underperformance in mathematics in the classroom.

## Mathematics anxiety

Mathematics anxiety refers to the negative reaction that many people experience when placed in situations that require mathematical problem solving (Richardson and Suinn 1972). This reaction can range from seemingly minor frustration to overwhelming emotional and physiological disruption (Ashcraft and Moore 2009). In fact, it has been argued that mathematics anxiety can be considered a genuine phobia given that it is a state anxiety reaction, shows elevated physiological arousal, and is a stimulus-learned fear (Faust 1992). Strong negative reactions to mathematics have long caught the attention of educators. For example, in an anecdotal report, Gough (1954), a school teacher, noted that many of her students, predominantly the females, were exhibiting emotional difficulties with mathematics and were failing to learn the material. While this was one of the first mentions of what is now known as mathematics anxiety in an education or psychology journal, it was not until years later that Richardson and Suinn (1972) created the Mathematics Anxiety Rating Scale (MARS) which served as a catalyst for further investigation of math anxiety, spurring a plethora of research into the topic.

Using self-report scales such as the MARS, researchers have been able to grasp a firm understanding of the construct of mathematics anxiety and its consequences. Indeed, much of the early work on this topic is eloquently summarised in Hembree's (1990) meta-analysis. Highlights from Hembree include the findings that people high in mathematics anxiety (as measured by the MARS) hold several negative attitudes about mathematics; they believe that mathematics is not useful, they are unmotivated to engage in mathematics, and they tend to avoid elective mathematics courses and mathematics intensive careers (i.e., science, technology, engineering, and mathematics: STEM). Not only do people high in mathematics anxiety dislike and avoid mathematics, they also perform poorly in their mathematics courses and on standardised tests, which can greatly limit a person's options for universities and career paths. Interestingly, research indicates that once students have developed mathematics anxiety, their levels of anxiety tend to remain relatively constant (at least throughout middle and high school). As such, mathematics anxiety is often discussed as a relatively stable trait (Hembree 1990). Mathematics anxiety has been shown to be related to poor performance on a wide array of tasks, ranging from simple numerical tasks such as counting objects (Maloney et al. 2010) and comparing numbers (Maloney, Ansari and Fugelsang 2011) to more complex tasks such as addition with carrying (Ashcraft and Kirk 2001) and multistep calculations (Mattarella-Micke et al. 2011).

While much research has focused on developing reliable tools to assess mathematics anxiety, there is considerably less work on its causes. However, studies assessing the impact of various teaching styles on student anxiety may provide insight into the development of mathematics anxiety. For example, Turner et al. (2002) examined factors that led children to avoid mathematics and concluded that one cause of avoidance was having a teacher who conveyed a high demand for correctness in mathematics but provided little cognitive or motivational support during lessons. Turner et al. speculated that students with such teachers may feel "vulnerable to public displays of incompetence" (p. 101). Consistent with this claim, Ashcraft (2002) reports that his participants often cite public embarrassment in mathematics as a cause of their anxiety. Further research by Beilock et al. (2010) suggests that highly mathematics-anxious teachers affect their student's endorsement of negative stereotypes about mathematics. Beilock et al. (2010) assessed mathematics anxiety in a sample of American teachers (all female) of first- and second-grade (7–9 year old) students, as well as the mathematics achievement and gender stereotype endorsement of the students in these teachers' classrooms. There was no relation between a teacher's mathematics anxiety and her student's mathematics achievement at the beginning of the school year. However, by the end of the year, the more mathematics-anxious a teacher was, the lower her student's mathematics achievement and the higher the likelihood that her students would endorse the stereotype that "boys are good at mathematics, and girls are good at reading". Interestingly, this pattern was limited to female students, suggesting that seeing female teachers anxious about mathematics provided information to same-gendered students about their own ability in mathematics. Beilock et al. (2010) did not report the students' levels of mathematics anxiety, thus, we cannot know whether having a mathematics-anxious teacher leads to increased mathematics anxiety in the students. Nonetheless, it is likely that such characteristics in teachers (i.e., a high demand for correctness with little cognitive or emotional support, a high degree of mathematics anxiety themselves) are risk factors for the development of mathematics anxiety in their students.

In addition to the above research suggesting that mathematics anxiety may be socially transmitted, Maloney and colleagues (Maloney et al. 2010; Maloney et al. 2011; Maloney et al. 2012) have argued that some people may, in fact, be cognitively predisposed to develop mathematics anxiety. Maloney and colleagues argue that students who present with deficits in the basic building blocks of mathematics are likely to struggle with mathematics and consequently develop a great deal of anxiety when engaging in mathematics tasks. This theory is based on evidence that high mathematics-anxious adults perform more poorly than their low mathematics-anxious peers on tests of basic numerical and mathematical abilities. For example, when presented with a display of squares, ranging in number from 1–9, and asked to enumerate the set (i.e., how many squares are there?), high and low mathematics-anxious adults perform equally well when a small number of squares is presented (1–4). However, as the number of squares increases from 5–9, the high mathematics-anxious students become increasingly slower and less accurate than their low anxious peers (Maloney et al. 2010). Maloney and colleagues also demonstrated that when adult students were shown a number ranging from 1–4 or 6–9 and were asked to simply indicate whether that number was lower or higher than 5, the high mathematics-anxious students took longer to do so than the students low in mathematics anxiety (Maloney et al. 2011). It is against this background that Maloney and colleagues argue that mathematics anxiety is associated with – and possibly driven by – a low-level deficit in numerical processing.

The above findings may appear to suggest that mathematics anxiety is simply a proxy for poor mathematics achievement, and while this may have some validity, it is certainly not the entire story. Indeed, high mathematics-anxious students tend to perform poorly on tests of mathematics ability, but interventions that are designed to reduce anxiety (and provide no additional mathematics training, e.g., cognitive behavioral therapy) have been shown to yield significant increases in mathematics test scores for highly mathematics-anxious individuals (Hembree 1990). Thus, for highly anxious students, their scores on mathematics tests are not simply a representation of their mathematics knowledge, but rather their scores are likely depressed as a result of their anxiety.

Mathematics anxiety is clearly an impediment to mathematics achievement (e.g., Ashcraft and Ridley 2005; Maloney et al. 2010). That said, not all people with high mathematics anxiety perform poorly in mathematics. Lyons and Beilock (2011) used functional magnetic resonance imaging (fMRI) to investigate whether neural differences exist between the high mathematics-anxious students who perform poorly in mathematics and those who, despite their anxiety, perform well in mathematics.

In Lyons and Beilock's (2011) work, all participants, while in the MRI scanner, performed a mental arithmetic task where they had to identify whether an arithmetic problem had been correctly solved [for example: $(a \times b) - c = d$] and a difficulty matched word-verification task where the participant had to decide whether a letter string, if reversed, spelled an actual English word (for example: tnemirepxe). Not surprisingly, the researchers found that, on average, high mathematics-anxious individuals performed worse than their non-mathematics-anxious peers on the mathematics questions. In contrast, both groups performed the same on the word problems. This distinction is important in that it demonstrates that the poor performance associated with mathematics anxiety is specific to mathematics and mathematics-related tasks. In other words, high mathematics-anxious students are not simply underachieving across the board.

Crucially, in the Lyons and Beilock (2011) study, before each set of problems, individuals saw a cue (a coloured box) which indicated whether the next set of trials was going to be a mathematics set or a word set. The beauty of this paradigm is that it allowed the researchers to separate the neural activity associated with the *anticipation* of doing mathematics from the neural activity of actually doing the mathematics. Lyons and Beilock (2011) found that, when faced with the prospect of an upcoming mathematics problem, some highly mathematics- anxious individuals showed more activation of a frontoparietal network known to be involved in the control of negative emotions than others. In fact, the activation of this region predicted success among the highly mathematics-anxious individuals. The more the highly mathematics-anxious individuals activated this frontoparietal network *before* they even engaged in the mathematics, the better they performed on the mathematics task. To explain their finding, Lyons and Beilock suggested that the successful high mathematics-anxious participants may be engaging in some degree of reappraisal (or reframing the situation) before they begin the mathematics task, and that this reappraisal helps them control their anxiety and ultimately perform up to their potential on the mathematics test.

From Lyons and Beilock (2011), as well as Ashcraft and Kirk (2001), we begin to see evidence of the additional cognitive burden that mathematics anxiety places on mathematics-anxious individuals, and the negative ramifications of this burden on their mathematics performance. However, mathematics anxiety is not the only condition that creates suboptimal performance in mathematics. Indeed, stereotype threat causes similar cognitive impairments that also lead to underperformance in mathematics. Interestingly, both mathematics anxiety and stereotype threat are thought to share a common underlying mechanism. In the following section we discuss stereotype threat, highlighting the quintessential findings and what they mean for performance in mathematics overall, and then discuss the underlying mechanism common to both, which is thought to cause much of the poor performance associated with these two phenomena.

## Stereotype threat

Stereotype threat refers to the phenomenon whereby individuals perform more poorly than their ability dictates on a task when a relevant negative stereotype is made salient in the performance situation (Steele and Aronson 1995). For example, women perform worse when the stereotype that women are bad at mathematics is made salient than when it is not, African American students perform worse when they believe a test is designed to measure intelligence than when they do not, and white men perform worse in a sports contest when they believe the contest is about natural ability as compared to "sport intelligence" (Spencer, Steele, and Quinn 1999; Steel and Aronson 1995). It is believed that the poor performance results from concern that if an individual fails, then they might be viewed as confirming a negative social stereotype.

In the initial demonstration of the stereotype threat phenomenon, researchers asked African American and white students to perform a subset of problems taken from the verbal section of the graduate record exam (GRE). When the task was described as a problem-solving task that was not diagnostic of ability (the non-stereotype threat condition), both groups performed the same. However, when the task was described as diagnostic of intelligence, the African American students performed significantly worse than the white students. Steele and Aronson (1995) theorised that describing the test as a measure of intelligence activated a stereotype about race and intelligence. The end result was that the African American students, being made aware of the stereotype, underperformed or "choked", only to perform in a stereotypical manner.

While the first empirical demonstration of this effect dealt with stereotypes about African Americans' performance on tests of verbal ability, subsequent research has demonstrated that the stereotype threat effect can apply to virtually anyone, so long as a stereotype exists for both the activity being tested and the group to which the individual belongs. Of particular importance to the current paper is the finding that women are quite susceptible to experiencing stereotype threat in situations where they are to perform mathematics. For example, Beilock, Rydell, and McConnell (2007) tested women on a multi-step mathematics problem. They had two groups, a stereotyped group and a control group. Both groups first did a set of mathematics problems, which served as a measure of baseline level of their mathematics ability. Then, the stereotyped group was told that the task was being used to investigate why women do worse than men on mathematics, while the control group was told that the researchers were studying problem solving. Both groups then completed a post-test of mathematics ability. In the threatened group (i.e., those told that the study was investigating gender differences in mathematics), accuracy dropped 10% from baseline to post-test; whereas the control group actually saw an increase in accuracy (likely due to practice). Indeed, stereotype threat can be induced in women taking a mathematics test by simply asking them to identify their gender before the test (Stricker and Ward 2004; Danaher and Crandall 2008).

While nearly everyone is susceptible to stereotype threat, there are individual differences in the degree to which people are affected by it. Indeed, not all individuals within a stigmatised group are destined to perform poorly. Various factors have been identified among those predisposed to choke under stereotype threat pressure. For example, people who place a strong importance on success in a particular domain (i.e., have strong domain identity) are more likely to perform worse under stereotype threat than those who do not place a high degree of importance on success in the domain (Cadinu et al.2003; Leyens et al. 2000; Spencer et al. 1999). One theory is that for those with strong domain identity, success (and failure) becomes very self-relevant, and thus the consequence of failing is not only confirming a negative stereotype but it is also a threat to one's identity. Furthermore, the degree to which one identifies with a particular group (e.g., gender identity) increases the likelihood that one will perform poorly when faced with a negative stereotype about their group (Marx, Stapel, and Muller 2005; Polyhart, Ziegert, and McFarland 2003; Schmader, 2002). Finally, an individual's own prior awareness of negative societal expectations of success (what is referred to as stigma consciousness; Pinel 1999) also strongly influences the degree to which the student will fall prey to stereotype threat. As such, research has indicated that women who value mathematics, identify strongly with being a woman, and are familiar with the social stereotype that women are not strong in mathematics, are the most likely candidates to fall prey to the pressure of stereotype threat.

## Mathematics anxiety, stereotype threat and working memory

Given that both mathematics anxiety and stereotype threat lead to underachievement in mathematics, it is no surprise that a great deal of research has been dedicated to understanding these phenomena. Although mathematics anxiety and stereotype threat are thought to be distinct constructs with differing etiologies, researchers studying these phenomena have come to some similar conclusions regarding how affective factors interact with the cognitive processes that underlie mathematics. Specifically, both mathematics anxiety and stereotype threat are thought to compromise the working memory capacity that individuals have available for mathematics performance.

*Working memory* is commonly viewed as a limited capacity system that integrates, computes, stores, and manipulates the information to which a person is attending (Baddeley 2000; Engle 2002; Miyake and Shah 1999). Although there are a number of working memory models that differ on both structural and functional dimensions

(Miyake and Shah 1999), this paper focuses on one of the most commonly accepted models: Baddeley's (2000) multicomponent model. According to this framework, there exists a domain-general central executive that controls and coordinates the information that is active in working memory at any given time. There are also two domain-specific short-term stores; the phonological loop for acoustic/verbal information and the visual-spatial sketchpad for visual images. A fourth component, the episodic buffer, serves to bind information from the phonological loop, the visual–spatial sketchpad, and long-term memory into a unitary episodic representation.

Perhaps more relevant to the present discussion, however, is the importance of working memory for mathematics performance (e.g., De Rammelaere, Stuyven, and Vandierendonck 1999; Imbo and LeFevre 2010; Seyler, Kirk, and Ashcraft 2003). While adults can perform very basic arithmetic (e.g., $1 + 2$) by directly retrieving the answer, more complex calculations (e.g., $24 - 17/5$) require working memory resources (DeCaro et al. 2010). In terms of both mathematics anxiety and stereotype threat, when the individual begins to experience negative thoughts and ruminations about the consequences of doing poorly, these thoughts can occupy valuable working memory resources that would otherwise be allocated to the mathematics task at hand (e.g., Ashcraft and Kirk 2001; Beilock, Rydell, and McConnell 2007). An individual ends up in essentially a dual-task environment in which they are both attending to the negative thoughts and attempting the mathematics problems. As a result, mathematics performance suffers.

Evidence supporting the notion that mathematics anxiety causes an online reduction in working memory capacity comes from a number of empirical studies, with the first being work by Ashcraft and Kirk (2001; for a review of other related work see Beilock 2010). Ashcraft and Kirk presented high and low mathematics-anxious individuals with addition problems. Importantly, they manipulated the working memory demands of the problems by having problems that either required a carry operation in order to be answered correctly (e.g., $23 + 17$), making them questions that make high demands on working memory, or did not require a carry operation (e.g., $23 + 11$), making them less demanding questions in this respect. The participants performed these calculations under high and low verbal working memory loads. They were presented with either two letters (low working memory load) or six letters (high working memory load) before each addition problem, and after participants responded to the problem, they were asked to recall the letters in order.

Ashcraft and Kirk (2001) hypothesised that if mathematics anxiety ties up working memory resources, then as questions become more working memory demanding, the performance differences between high and low mathematics-anxious students should become increasingly larger. This was indeed the case. What is most interesting, however, is that on carry problems, the high mathematics-anxious individuals made approximately 40% errors in the high working memory load condition, whereas their low mathematics-anxious peers made approximately 20% errors. This error difference was much larger than it was on the carry problems under low load. These finding suggest that mathematics anxiety is not simply a proxy for poor math skill. If it was, then you would not expect the high mathematics-anxious individuals to suffer significantly more than the low mathematics-anxious people on problems in the high relative to low working memory load conditions, as the problems in both conditions involved carry operations. Rather, these findings are more parsimonious with the claim that high mathematics-anxious individuals suffer from a decreased working memory capacity relative to their non-mathematics-anxious peers when they do mathematics. As a result, mathematics-anxious individuals experience a large decrement on the working memory demanding (i.e., carry) mathematics questions when they are paired with an additional large memory load. This study is important as it is one of the first empirical studies to demonstrate a potential mechanism by which mathematics anxiety is related to poor mathematics performance (i.e., an anxiety-induced reduction in working memory capacity). It also sheds light on the importance of conducting empirical research around issues of affect and anxiety in mathematics. Namely, work such as that of Ashcraft and Kirk (2001) goes against the notion that math anxiety is purely a proxy for poor math skills, and thus sets the stage for exploring the negative cognitive and emotional consequences of mathematics anxiety and how to alleviate them.

Similarly, research in the stereotype threat literature also suggests that, when threatened, people experience negative thoughts and rumination, which leads to a temporary reduction in working memory capacity and, consequently, poor performance. Just as the empirical work by Ashcraft and Kirk (2001) was pivotal for our understanding of mathematics anxiety, empirical work by Schmader and Johns (2003) greatly furthered our understanding of stereotype threat. Schmader and Johns (2003) had women complete a working memory task in which they had to evaluate mathematical equations while remembering words for later recall, and also a difficult mathematics task either in a stereotype threat or no threat condition. They found that women in the stereotype threat condition, where the test was described as a measure of mathematical ability, showed reduced working memory capacity (i.e., they could recall fewer words) and poorer mathematics test performance relative to the control group. Furthermore, working memory capacity acted as a mediator between stereotype threat and poor mathematics performance, suggesting a causal relationship. Put another way, both stereotype threat and working memory capacity predicted mathematics performance, but, when working memory capacity was controlled for, stereotype threat no longer predicted mathematics performance. Thus, it appears that the mechanism by which stereotype threat is related to mathematics performance is via a reduction in working memory capacity (see also Beilock et al. 2007; Croizet et al. 2004 for similar findings).

Both mathematics anxiety and stereotype threat are thought to share a similar mechanism (i.e., a negative rumination-induced reduction in working memory capacity) by which mathematics performance is disrupted. As such, it follows that interventions that are designed to limit this working memory reduction may serve as promising remedies for both mathematics anxiety and stereotype threat. Below, we detail two such interventions.

## Remediation of mathematics anxiety and stereotype threat

In light of the evidence that negative thoughts and worries causes students to underperform in mathematics, several researchers are currently looking to develop remediation techniques to help increase performance in mathematics-anxious and stereotyped students. Particularly promising, are interventions that are designed to combat the effects of negative thoughts and ruminations on working memory capacity. One such intervention involves the use of expressive writing. For example, Ramirez and Beilock (2011) asked high school students, ten minutes before an upcoming exam, to write about their feelings regarding the exam. Ramirez and Beilock theorised that having the students engage in an expressive writing exercise would help to alleviate the intrusive thoughts that result from anxiety related to performance, and thus would free up working memory resources. They took measures of students' test anxiety (the degree of anxiety that they feel within a typical testing situation) six weeks before their final exam. Previous research has indicated a negative relation between test anxiety and test performance similar to that seen in mathematics anxiety and stereotype threat. Then, on the day of the final exam, Ramirez and Beilock asked about half of the students to think about a topic that would not be in their exam for 10 minutes (the control condition), and asked the other half of the students to write openly about their feelings towards the upcoming exam for 10 minutes (the expressive writing group). The results indicated that the expressive writing exercise was indeed successful, as the students in the expressive writing group had higher overall scores than those who did not write about the upcoming test. Ramirez and Beilock (2011) were further interested in investigating whether all students in the expressive writing condition benefitted equally by the exercise, or if some students were helped more than others. They hypothesised that perhaps the students who suffer the most from test anxiety would receive the biggest benefit. To test this idea, the authors used the test anxiety scores collected prior to the experiment and divided the students into two groups; those with the highest levels of test anxiety, and those with the lowest. Sure enough, the students with the highest levels of test anxiety were the same students who benefitted the most from the expressive writing exercise. Indeed, the high test-anxious students who engaged in expressive writing had final exams scores that were as high as the low test-anxious students. Interestingly, the simple act of writing alone was not enough to equate the two groups. When Ramirez and Beilock asked students to write about their day (rather than about the upcoming test), they found there was no significant benefit from the writing. While the expressive writing technique was first applied to address test anxiety, recent research indicates that it is also effective in increasing mathematics scores in mathematics-anxious students (Park, Ramirez, and Beilock 2011). Thus, expressive writing may have a wide variety of applications.

Another way to alleviate the effects of anxiety on working memory is to teach anxious students to reappraise their arousal or, put another way, to re-contextualise the situation. Schmader and colleagues have demonstrated that there are at least two ways that students can be taught to reappraise their anxiety when under stereotype threat. For example, Jamieson et al. (2010) had students come into the lab and take a practice test for an upcoming high stakes test. Half of the students were told that arousal actually helped with performance (the reappraisal condition), while the other half was told nothing (the control condition). Interestingly, the students in the reappraisal condition performed significantly better than the control group both on the practice exam, and also on the actual high stakes test months later. In another study, Johns, Schmader and Martens (2005) were able to eliminate the effect of stereotype threat by simply teaching women about the phenomenon and the anxiety that it might produce. Men and women completed difficult mathematics problems that were described either as a problem-solving task (the control group) or as a mathematics test (the stereotype threat group). A third group was also told that the task was a mathematics test (a stereotype induction), but participants were additionally informed that stereotype threat could make women feel more anxious (the reappraisal group). The study replicated the standard finding that women performed worse than men when the problems were described as a mathematics test (and stereotype threat was not discussed) and the women did not differ from the men in the control condition. Importantly, women did not differ from men in the condition in which they learned about stereotype threat. In other words, simply teaching the women about stereotype threat allowed them to reappraise the arousal that they felt (most likely attributing the arousal to stereotype threat rather than attributing it to a high degree of pressure to succeed), and consequently inoculated them against stereotype threat. Given that Lyons and Beilock (2011) found that high mathematics-anxious students who succeeded in mathematics activated areas of the brain known to be involved in reappraising negative emotions before they took part in a mathematics task, the above mentioned reappraisal interventions hold promise for eradicating the negative impact of both mathematics anxiety and stereotype threat on mathematics performance.

Although the aforementioned interventions may prove effective remediations for both mathematics anxiety and stereotype threat, it is important to point out that while mathematics anxiety and stereotype threat are both thought to impact online working memory capacity, they are not thought to arise for the same reasons. As such, while it is important to have interventions that serve to decrease the impact of anxiety on performance in mathematics, it is also important to have interventions that serve to prevent this anxiety from ever developing. We next discuss some potential methods of preventing the development of mathematics anxiety and stereotype threat.

With regard to mathematics anxiety, there are currently no known interventions designed to prevent its onset. This is, in large part, because the exact etiology of mathematics anxiety remains unknown. That said, Maloney and colleagues' research, indicating that mathematics anxiety may stem from a basic deficit in numerical processing, suggests that children who present with poor number processing skills may be the most likely to develop mathematics anxiety. If this is, indeed, the case, then for children who present with a numerical processing deficit early on in development, the focus should be on increasing their numerical processing skills. It is possible that employing training methodologies that focus on strengthening numerical skills may be a useful tool for the children most at risk of developing mathematics anxiety (see Maloney and Beilock 2012).

Further, the research by Beilock et al. (2010), demonstrating that teachers with high mathematics anxiety can transmit their stereotypes to their students, suggests that interventions to decrease a teacher's level of mathematics anxiety may result in the reduction (or even elimination) of mathematics anxiety in hundreds of students over the course of her career. In fact, work by Tooke and Lindstrom (1998) suggests that teaching interventions can be developed which serve to decrease levels of mathematics anxiety in teachers (i.e., teaching pre-service teachers to focus on how children learn mathematics rather than teaching them the actual mathematics). Furthermore, given that mathematics-anxious teachers can influence their female students in terms of endorsement of negative gender stereotypes about girls and mathematics, it is feasible that girls in the classrooms of female mathematics-anxious teachers may experience stereotype threat. Thus, if we can employ some of the previously mentioned reappraisal techniques both with the teachers and with young children, then we may be able to prevent young girls from falling prey to the negative consequences of stereotype threat as it pertains to mathematics.

## Conclusions

In the current paper we have discussed the negative consequences of students' anxiety on assessments of mathematics proficiency and have argued that, for many students', mathematics tests are capturing far more than their mathematics knowledge. While highlighting some of the various experimental methods used to examine the influence of affective factors on mathematics performance (for example, questionnaires, experimental manipulations, and neuroimaging), we have demonstrated that, indeed, for many students their scores on tests of mathematics achievement are depressed by anxieties felt towards mathematics. Synthesising research from the studies of mathematics anxiety and stereotype threat, we have argued that performance anxiety co-opts valuable working memory resources that are necessary for complex mathematics. We further argue that it may be the case that some students are cognitively predisposed to develop mathematics anxiety (i.e., those with poor number processing skills; Maloney et al., 2010–12), and that some students are more likely to fall victim to stereotype threat (i.e., those who identify strongly with the stereotyped domain and group, those who are aware of the existence of the particular stereotype, and those students for whom stereotypes may be modeled or endorsed by their teacher's anxiety about their own mathematics ability). Finally, we have suggested methods for reducing the negative consequences of anxiety and stereotype threat on mathematics.

Here, we summarised many of the newest advancements in mathematics anxiety and stereotype threat research. While much progress has been made in recent years, there are a number of interesting questions that have yet to be answered, one of which is the question of cultural differences in mathematics anxiety and stereotypes about mathematics. While it is clear that mathematics anxiety is prevalent in North America (e.g., Maloney and Beilock 2012) and in Europe (e.g., Krinzinger, Kaufmann, and Wilmes 2009; Devine et al. 2012), further research may want to examine the profiles of mathematics anxiety in different locations to determine whether antecedents, age of acquisition, and remediations are the same across various cultures. With respect to social stereotypes about mathematics, research indicates that the social stereotype that men are more skilled in mathematics than women is one that is very widely held (Nosek et al. 2009). Not only is the gender stereotype widely held, but nation-level stereotypes about mathematics strongly predict gender gaps within nations (Nosek et al. 2009), suggesting that girls in many countries can fall prey to stereotypes about who is skilled in mathematics.

As demonstrated by the work reviewed here, empirical research can help elucidate the cognitive mechanisms that drive the relationship between negative math-related emotional responses and poor math performance, and can also help answer questions about cultural variation. Such research allows for thorough understanding of the factors that can influence students' achievement in mathematics, and is essential for creating effective performance environments that ensure all students achieve their best in school.

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## References

Ashcraft, M. 2002. Math anxiety: Personal, educational, and cognitive consequences. *Current Directions in Psychological Science* 115: 181–5. doi:10.1111/1467-8721.00196.

Ashcraft, M., and E. Kirk. 2001. The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General* 1302: 224–37. doi:10.1037/0096-3445.130.2.224.

Ashcraft, M., and A. Moore. 2009. Mathematics anxiety and the affective drop in performance. *Journal of Psychoeducational Assessment* 273: 197–205. doi:10.1177/0734282908330580.

Ashcraft, M., and K. Ridley. 2005. Math anxiety and its cognitive consequences: A tutorial review. In *Handbook of mathematical cognition*, ed. J. Campbell, 315–27. New York: Psychology Press.

Baddeley, A. 2000. The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences* 411: 417–23. doi:10.1016/S1364-6613(00)01538-2.

Beilock, S.L. 2010. *Choke: What the secrets of the brain reveal about getting it right when you have to*. Simon and Schuster: Free Press.

Beilock, S.L., E.A. Gunderson, G. Ramirez, and S.C. Levine. 2010. Female teachers' math anxiety affects girls' math achievement. *Proceedings of the National Academy of Sciences, USA* 1075: 1060–3.

Beilock, S.L., R.J. Rydell, and A.R. McConnell. 2007. Stereotype threat and working memory: Mechanisms, alleviation, and spill over. *Journal of Experimental Psychology: General* 136: 256–76. doi:10.1037/0096-3445.136.2.256.

Candinu, M., A. Maass, S. Frigerio, L. Impagliazzo, and S. Latinotti. 2003. Stereotype threat: The effect of expectancy on performance. *European Journal of Social Psychology* 332: 267–85. doi:10.1002/ejsp.145.

Croizet, J., G. Despres, M. Gauzins, P. Huguet, J. Leyens, and A. Meot. 2004. Stereotype threat undermines intellectual performance by triggering a disruptive mental load. *Personality and Social Psychology Bulletin* 306: 721–31. doi:10.1177/0146167204263961.

Danaher, K., and C. Crandall. 2008. Stereotype threat in applied settings re-examined. *Journal of Applied Social Psychology* 386: 1639–55. doi:10.1111/j.1559-1816.2008.00362.x.

Devine, A., K. Fawcett, D. Szűcs, and A. Dowker. 2012. Gender differences in mathematics anxiety and the relation to mathematics performance while controlling for test anxiety. *Behavioral and Brain Functions* 8: 33. doi:10.1186/1744-9081-8-33.

DeCaro, M.S., K.E. Rotar, M.S. Kendra, and S.L. Beilock. 2010. Diagnosing and alleviating the impact of performance pressure on mathematical problem solving. *The Quarterly Journal of Experimental Psychology: Human Experimental Psychology* 638: 1619–30. doi:10.1080/17470210903474286.

De Rammelaere, S., E. Stuyven, and A. Vandierendonck. 1999. The contribution of working memory resources in the verification of simple mental arithmetic sums. *Psychological Research* 62: 72–7. doi:10.1007/s004260050041.

Engle, R. 2002. Working memory capacity as executive attention. *Current Directions in Psychological Science* 111: 19–23. doi:10.1111/1467-8721.00160.

Faust, M.W. 1992. Analysis of physiological reactivity in mathematics anxiety. PhD diss., Bowling Green State University, Ohio.

Gough, M.F. 1954. Mathemaphobia: Causes and treatments. *Clearing House* 28: 290–4.

Hembree, R. 1990. The nature, effects, and relief of mathematics anxiety. *Journal for Research in Mathematics Education* 211: 33–46. doi:10.2307/749455.

Imbo, I., and J. LeFevre. 2010. The role of phonological and visuo-spatial working memory in complex arithmetic problem solving. *Memory and Cognition* 38: 176–85. doi:10.3758/MC.38.2.176.

Jamieson, J., W.B. Mendes, E. Blackstock, and T. Schmader. 2010. Turning the knots in your stomach into bows: Reappraising arousal improves performance on the GRE. *Journal of Experimental Social Psychology* 46: 208–12. doi:10.1016/j.jesp.2009.08.015.

Johns, M., T. Schmader, and A. Martens. 2005. Knowing is half the battle: Teaching stereotype threat as a means of improving women's math performance. *Psychological Science* 163: 175–9. doi:10.1111/j.0956-7976.2005.00799.x.

Krinzinger, H., L. Kaufmann, and K. Willmes. 2010. Math anxiety and math ability in early primary school years. *Journal of Psychoeducational Assessment* 27: 206–25. doi:10.1177/0734282908330583.

Leyens, J., M. Desert, J. Croizet, and C. Darcis. 2000. Stereotype threat: Are lower status and history of stigmatization preconditions of stereotype threat? *Personality and Social Psychology Bulletin* 2610: 1189–99. doi:10.1177/0146167200262002.

Lyons, I.M., and S.L. Beilock. 2012. Mathematics anxiety: Separating the math from the anxiety. *Cerebral Cortex* 22: 2102–10. doi:10.1093/cercor/bhr289.

Maloney, E.A., and S.L. Beilock. 2012. Math anxiety: Who has it, why it develops, and how to guard against it. *Trends in Cognitive Sciences* 16: 404–6. doi:10.1016/j.tics.2012.06.008.

Maloney, E.A., D. Ansari, and J.A. Fugelsang. 2011. The effect of mathematics anxiety on the processing of numerical magnitude. *The Quarterly Journal of Experimental Psychology* 641: 10–6. doi:10.1080/17470218.2010.533278.

Maloney, E.A., E.F. Risko, D. Ansari, and J.A. Fugelsang. 2010. Mathematics anxiety affects counting but not subitizing during visual enumeration. *Cognition* 1142: 293–7. doi:10.1016/j.cognition.2009.09.013.

Maloney, E.A., S. Waechter, E.F. Risko, and J.A. Fugelsang. 2012. Reducing the sex difference in math anxiety: The role of spatial processing ability. *Learning and Individual Differences* 22: 380–4. doi:10.1016/j.lindif.2012.01.001.

Marx, D., D. Stapel, and D. Muller. 2005. We can do it: The interplay of construal orientation and social comparisons under threat. *Journal of Personality and Social Psychology* 883: 432–46. doi:10.1037/0022-3514.88.3.432.

Mattarella-Micke, A., J. Mateo, M.N. Kozak, K. Foster, and S.L. Beilock. 2011. Choke or thrive? The relation between salivary cortisol and math performance depends on individual differences in working memory and math anxiety. *Emotion* 114: 1000–5. doi:10.1037/a0023224.

Miyake, A., and P. Shah. 1999. Models of working memory: Mechanisms of active maintenance and executive control. New York: Cambridge University Press.

Nosek, B. A., F.L. Smyth, N. Sriram, N.M. Lindner, T. Devos, A. Ayala, Y. Bar-Anan, R. Bergh, H. Cai, K. Gonsalkorale, S. Kesebir, N. Maliszewski, F. Neto, E. Olli, J. Park, K. Schnabel, K. Shiomura, B. Tulbure, R.W. Wiers, M. Somogyi, N. Akrami, B. Ekehammar, M. Vianello, M.R. Banaji, and A.G. Greenwald. 2009. National differences in gender–science stereotypes predict national sex differences in science and math achievement. *Proceedings of the National Academy of Sciences*, USA: 593–7.

Park, D., G. Ramirez, and S.L. Beilock. 2011. Put your math burden down: Expressive writing for the highly math anxious. Paper presented at the Midwestern Psychology Association, Chicago, IL.

Pinel, E. 1999. Stigma consciousness: The psychological legacy of social stereotypes. *Journal of Personality and Social Psychology* 761: 114–28. doi:10.1037/0022-3514.76.1.114.

Polyhart, R., J. Ziegert, and L. McFarland. 2003. Understanding racial differences on cognitive ability tests in selection contexts: An integration of stereotype threat and applicant reactions research. *Human Performance* 163: 231–59. doi:10.1207/S15327043HUP1603_4.

Ramirez, G., and S.L. Beilock. 2011. Writing about testing worries boosts exam performance in the classroom. *Science* 331: 211–3. doi:10.1126/science.1199427.

Richardson, F., and R. Siunn. 1972. The mathematics anxiety rating scale: Psychometric data. *Journal of Counseling Psychology* 196: 551–4. doi:10.1037/h0033456.

Schmader, T. 2002. Gender identification moderates the effects of stereotype threat on women's math performance. *Journal of Experimental Social Psychology* 38: 194–201. doi:10.1006/jesp.2001.1500.

Schmader, T., and M. Johns. 2003. Converging evidence that stereotype threat reduces working memory capacity. *Journal of Personality and Social Psychology* 854: 440–52. doi:10.1037/0022-3514.85.3.440.

Seyler, D., E. Kirk, and M. Ashcraft. 2003. Elementary subtraction. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 296: 1339–52.

Spencer, S., C. Steele, and D. Quinn. 1999. Stereotype threat and women's math performance. *Journal of Experimental Social Psychology* 351: 4–28. doi:10.1006/jesp.1998.1373.

Steele, C., and J. Aronson. 1995. Stereotype threat and the intellectual test performance of African Americans. *Journal of Personality and Social Psychology* 695: 369–89.

Stricker, L., and W. Ward. 2004. Stereotype threat, inquiring about test takers' ethnicity and gender, and standardized test performance. *Journal of Applied Social Psychology* 344: 665–93. doi:10.1111/j.1559-1816.2004.tb02564.x.

Tooke, D.J., and L.C. Lindstrom. 1998. Effectiveness of a mathematics methods course in reducing math anxiety of preservice elementary teachers. *School Science and Mathematics* 983: 136–9. doi:10.1111/j.1949-8594.1998.tb17406.x.

Turner, J.C., C. Midgley, D.K. Meyer, M. Ghenn, E.M. Anderman, and Y. Kang. 2002. The classroom environment and students' reports of avoidance strategies in mathematics: A multi method study. *Journal of Educational Psychology* 94: 88–106. doi:10.1037/0022-0663.94.1.88.