Overview

Anxiety and cognition

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In this review we discuss the interplay between anxiety and cognition, illustrating how anxiety can compromise performance on cognitively-demanding tasks and lead people to perform below their ability. Using math anxiety and test anxiety as examples, we highlight key findings from psychology, cognitive science, and neuroscience, to show that how one approaches an anxiety-inducing situation can have a large impact on how that person ultimately performs. We end by discussing who is most susceptible to anxiety-induced poor performance and suggest promising techniques which may help to reduce the negative impact of anxiety on performance. © 2014 John Wiley & Sons, Ltd.

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INTRODUCTION

Encountering stressors is virtually unavoidable in our daily lives and can have marked impacts on our performance. While some arousal can lead to optimal performance, too much can result in anxiety that can cause us to 'choke' or to perform below our abilities.[1] Although some research suggests that there may be situations in which there is no upper bound to the positive association between arousal and performance,[2] in other situations performance is optimal at intermediate levels of arousal and decreases when arousal is too high.[3,4] In this review, we discuss such situations.

For example, whether it is taking a high-stakes test or doing a difficult math problem, we often experience such high degrees of arousal that anxiety ensues. Anxiety, an aversive emotional state that occurs in situations of real or perceived threat, has physiological correlates and is characterized by a sense of apprehension and worry.[5]

We discuss two types of anxiety that are commonly experienced in academic situations—test anxiety and math anxiety. Summarizing psychological, physiological, and neuroscience research highlighting the negative consequences of these anxieties, we suggest that, although these types of anxiety have different etiologies, they have similar physiological and cognitive manifestations. We demonstrate that not everyone are equally susceptible to the negative consequences of anxiety by discussing psychological characteristics that may distinguish those who perform poorly from those who succeed in situations that require us to perform at our best. We conclude by highlighting promising interventions that may prove effective at reducing anxiety's negative impact on performance.

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TEST ANXIETY

Test anxiety, which refers to anxiety that is felt in testing situations, is a commonly experienced form of anxiety that is associated with poor exam scores.[6] This anxiety begins to appear in children as young as second grade and then increases grade by grade, with consistently higher levels for girls than for boys.[7] It has been estimated that as many as 25% of American primary and secondary school students (i.e., 1 in 4 children) suffer from some form of test anxiety.[8] High levels of test anxiety are linked to poor academic performance, lower marks in school, and increased grade repetition. In a meta-analysis of studies conducted in the United States and Europe, Seipp[9] suggested that the size of the negative correlation between test anxiety and achievement ($r = -.21$), when translated into academic test performance, meant that low-test-anxious students would outscore high-test-anxious students by about half of a standard deviation.

While test anxious students achieve lower marks than their nonanxious peers, it is not thought to be the case that these students are simply less competent than their less-anxious counterparts. Indeed, under neutral or reassuring conditions, high- and low-test-anxious students have been shown to not differ in performance levels[10] suggesting that the anxiety itself, rather than intelligence differences between the high- and low-anxious individuals, can explain much of the differences in academic outcomes. Of course, such a suggestion begs the question of where test anxiety comes from. Some researchers have suggested that a strong focus on and high prevalence of testing (as is the case within the American educational system) could cause some students to develop high levels of test anxiety,[11] and others have claimed that the development of test anxiety may largely depend upon the relation of one's own academic abilities relative to the abilities of the students who surround them.[12,13] Although the exact developmental trajectory of test anxiety is not yet known, what we do know is that it is becoming more and more prevalent within our educational system[11] and is deserving our attention.

MATH ANXIETY

Similar in many ways to test anxiety, math anxiety refers to feelings of fear, apprehension, or dread that many people experience when they are in situations that require solving math problems.[14] Whereas test anxiety is associated with decreased academic performance in general, math anxiety is associated specifically with decreased performance in math. In other words, those who are anxious about math tend to do poorly in math despite normal performance in other subject areas. Individuals who are high in math anxiety tend to have low math self-confidence, experience little or no enjoyment of math, and avoid math and math-related careers.[15] Interestingly, math anxiety is not only experienced in formal testing situations; even mundane everyday tasks, such as calculating a tip at a restaurant, can be enough to lead to the experience of anxiety in some people.[16]

Like test anxiety, math anxiety is more common in females than males and begins to appear in children as young as first and second grade[17,18] and increases as children get older.[15] Current estimates postulate that nearly 20% of the population (i.e., 1 in 5) suffer from a high degree of math anxiety.[19] While it seems reasonable to propose that those who are high in math anxiety are simply the students who are less competent in math, it is certainly not the entire story.[20–22] Indeed, interventions designed to reduce math anxiety have shown that, just like test anxiety, math anxiety actually causes students to perform at a level below their potential.[15,23]

Most of the research on math anxiety has focused on its negative consequences and not on its antecedents. However, recent research suggests that math anxiety may stem from both social and cognitive factors. Beilock et al.[24] suggest that negative attitudes about math may be passed down from mentors to mentees. Beilock et al. looked at the effect on students' math attitudes and math performance when their elementary school teachers were either high or low in math anxiety. For girls, if they were in a classroom taught by a highly math anxious teacher then by the end of the school year they were more likely to endorse the stereotype that boys are good at math and girls are good at reading. Furthermore, girls in the classrooms of high-math-anxious teachers also learned less math over the course of the school year relative to their peers who had teachers who were not anxious about math. Interestingly, having a teacher who was highly anxious about math did not affect the boys' attitudes about math or how much math they learned over the course of the school year to the same degree as the girls. In light of these findings, Beilock et al. argued that math anxiety and math attitudes are, in many ways, social constructs that can be transmitted from one generation to the next.

While there is undoubtedly a social component to the anxiety that many people experience when engaging in math tasks, there may also be cognitive factors that predispose people to develop math anxiety. Maloney et al.[22,25,26] have demonstrated that adults with math anxiety tend to struggle with many of the building blocks of math. For example, Maloney et al.[25] presented high- and low-math-anxious adults with a display containing from 1 to 9 squares and participants were simply asked to enumerate the number of squares on the screen. When there were five or more squares presented, the high-math-anxious adults were slower and less accurate at enumerating the squares, indicating a difficulty with a basic building block of mathematics. In light of this finding, and the fact that high-math-anxious adults have difficulty with other basic building block tasks (e.g., number comparison and spatial processing[22,26]), Maloney et al. suggest that children with poor numerical skills may be cognitively predisposed to develop math anxiety. Indeed, children who start formal schooling with deficiencies in these mathematical building blocks may be especially predisposed to pick up on social cues (e.g., their teacher's behavior) that highlight math in negative ways.

From the above descriptions of test anxiety and math anxiety, it is clear that these phenomena are different constructs. Indeed, correlations between test anxiety and math anxiety are only in the ($r = .52$)

range,[17] and recent research[21] has shown that, while test anxiety and math anxiety are positively correlated, math anxiety continues to negatively impact math performance even after controlling for test anxiety (at least for female students). Nonetheless, test anxiety and math anxiety do share a number of commonalities. Perhaps most obvious is that each is associated with people performing at a level below that of their natural abilities. Also striking, as we will soon discuss, is that the mechanisms by which performance suffers in each of these phenomena are similar. Said another way, test anxiety and math anxiety, despite being different constructs, share some of the same physiological and cognitive manifestations.

Regardless of the type of anxiety that we experience, such anxiety is often accompanied by physical and psychological changes. In the upcoming sections we outline the most common physiological reactions to and the cognitive consequences of anxiety, explaining how these physiological and cognitive changes can ultimately lead to worse performance than our ability dictates in situations where there is a desire to perform at a high level.[1] This multifaceted relation in which anxiety may lead to decreases in cognitive performance is outlined in Figure 1. As we will assert, anxiety-induced disruptions in performance can occur via two pathways: (1) anxiety can cause physiological changes (e.g., increased heart rate) and regulating these physiological changes requires the same neural resources as cognitively demanding tasks and (2) anxiety causes negative thoughts and ruminations which occupy the same cognitive resources necessary for successful performance on cognitively demanding tasks. Each of these pathways is explained in detail below.

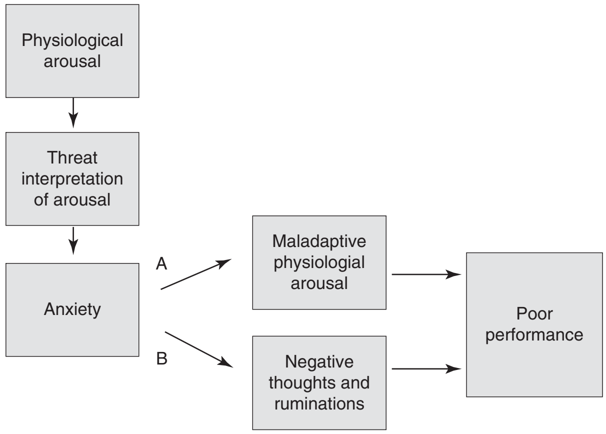

FIGURE 1 | Physiological arousal, if interpreted as a threat rather than as a challenge, can lead to negative emotions such as anxiety.[25] Anxiety can impact cognitively demanding tasks via two routes; (A) anxiety leads to maladaptive physiological changes and regulating these physiological changes requires the same neural regions that are necessary for performing cognitively demanding tasks[27,28] and (B) anxiety can cause negative thoughts and ruminations that occupy the working memory resources needed for the primary task.[18,29]

PHYSIOLOGIAL RESPONSES TO ANXIETY AND THEIR RELATION TO ACADEMIC PERFORMANCE

The experience of anxiety is one that often involves both the body and the mind. Indeed, the way that we use our minds to interpret a physically arousing situation can have a strong influence on how we perform in that situation. To understand how our psychological interpretation of our physiological arousal can impact performance, take for instance this example from Jamieson et al.[30]; imagine that you are a skier staring down a steep, icy slope whose only way off the mountain is to plunge down this trail. Regardless of your affinity for skiing, this situation would likely elicit an increase in physiological arousal but your affinity for skiing may influence how you *interpret* this arousal. If you are an expert skier then you may experience excitement and believe that you possess the resources necessary to handle the difficult trail. Conversely, if you are new to skiing then you may be more likely to experience fear and assume that the trail is too difficult for your ability. The way in which you interpret the arousal is critical in that seeing the arousal as a challenge leads to adaptive physiological changes including increased cardiac efficiency which can in turn lead to *increased* performance. Conversely, seeing the arousal as a threat leads to anxiety which in turn leads to decreased performance.[30]

Interestingly, before even encountering the situation that would lead to experiencing anxiety (in this example staring down the ski slope), individuals possess certain motivational styles that influence how they will interpret and react to a threat: approach or avoidance.[31] While those who adopt an avoidant motivational style avoid engaging in anxiety-inducing situations in an attempt to prevent experiencing anxiety, those who adopt approach motivational styles face the anxiety-inducing situation head-on in an attempt to deal with potentially negative information. These motivation styles are particularly important in that research suggests that those who adopt an approach motivational style may be less likely to experience anxiety.[32] It is possible that those who adopt an approach motivational style may be more likely that those who adopt an avoidance motivational style to view situations as challenges rather than threats. For a discussion on this topic see Elliot.[33]

Below we describe the physiological and cognitive mechanisms by which the anxiety that arises once the situation has been viewed as a threat that negatively impacts performance.

When you interpret a situation as a threat, you experience anxiety, which can be conceptualized as the body's warning system that prepares us to act physically and mentally in potentially dangerous situations. To be able to operate optimally in the threatening situation the body prepares to fight or flee.[34] One potential reason that interpreting a situation as a threat and experiencing anxiety may lead to poor performance on cognitively demanding tasks is because, when we are anxious, we experience an increase in our muscle tension and activation of the sympathetic nervous system. This autonomic stimulation leads to an increase in heart rate, blood pressure, sweat gland activity, and respiration, as well as increased gastrointestinal and bladder activity.[27,28,34] Heart rate, for example, is influenced antithetically by both sympathetic and parasympathetic nervous system activity,[35] both of which are likely under prefrontal cortical influence.[36] [a] This link between the prefrontal cortex (e.g., the dorsal lateral prefrontal cortex, DLPFC) and heart rate may be critical to performance on cognitively demanding tasks as the DLPFC region is also used extensively in solving cognitively demanding tasks.[37,38] In other words, the physiological response to anxiety-inducing situations itself may create a 'competition' for prefrontal cortical resources that would otherwise be used for cognitive functioning, and this may lead to decreases in performance (because fewer prefrontal cortical resources available for cognitive processing means fewer cognitive resources available for the task). In Figure 1, this link between anxiety and poor performance, which runs through our anxiety-induced physiological arousal, is represented by pathway A.

The way that we appraise a situation can have strong effects on our performance. In further support for this idea, Lyons and Beilock[39] used functional magnetic resonance imaging (fMRI) to investigate what neural differences exist between the high math anxious students who perform poorly in math and those who, in spite of their anxiety, perform well. Lyons and Beilock had participants perform a mental arithmetic task in which they identified whether an arithmetic problem had been correctly solved [e.g., $(a \times b) - c = d$] and a difficulty matched word-verification task where the participant had to decide whether a letter string, if reversed, spelled an actual English word (e.g., tnemirepxe). Both tasks were completed in an fMRI scanner. While the high math anxious participants tended to score worse than their low math anxious peers on the math task, both groups performed equally well on the word task. This is, of course, not surprising given that math anxiety has been shown to affect math performance specifically. What was surprising, however, is that not all math anxious individuals behaved the same under pressure. Critically, before each set of problems, individuals saw a cue (a colored box) which indicated whether the next set of trials was going to be a math set or a word set. This cue allowed the researchers to separate the neural activity associated with the anticipation of doing math from the neural activity of actually doing the math. Lyons and Beilock found that a subset of high anxious individuals showed activation of a frontoparietal network when anticipating math problems including the inferior frontal junction (IFJ), the inferior parietal lobule (IPL), and the left inferior frontal gyrus (IFGa), a network in part known to be involved in the control of negative emotions.[40] Importantly, among high-math-anxious individuals, the activation of these regions during a math cue actually predicted the activation of two subcortical regions while performing the math task (right caudate nucleus and the left hippocampus). Activation in these subcortical regions mediated the relation between frontoparietal activation and deficits in math performance such that the more the anxious individuals activated these subcortical regions during the task (as predicted via frontoparietal activation during the math cue), the better they performed on the task. Lyons and Beilock interpreted these findings as evidence that the successful high math anxious participants may be more likely to be viewing the task as a challenge rather than as a threat and that this helps them to control their anxiety and manage the demands of math performance, ultimately performing up to their potential on the mathematics test.

THE COGNITIVE CONSEQUENCES OF ANXIETY

Although it is clear that anxiety can lead to changes in physiological arousal and these changes can be detrimental for performance on cognitively demanding tasks, it can also lead to negative cognitions, which, in turn, can negatively impact cognitively demanding tasks. When people feel anxious they often experience negative worries and ruminations, often about the consequence of underperforming.[41] An important distinction here is that anxiety-induced negative thoughts can occur in the absence of any anxiety-induced physiological arousal (i.e., people may become anxious and begin to ruminate about the consequences of doing poorly but may not experience the aforementioned physiological changes that often occur as a result of anxiety[42]). Importantly, however, negative thoughts and worries do tend to multiply when they are experienced along with an increase in physiological arousal.[43]

To understand how these thoughts and ruminations disrupt performance, one must first understand the concept of working memory. *Working memory* is commonly thought of as a limited capacity system that integrates, computes, stores, and manipulates the information to which a person is attending.[42,44,45] Although there are a number of working memory models that differ on both structural and functional dimensions,[45] here we focus on one of the most commonly accepted models: Baddeley's multicomponent model.[42] According to this model, there is 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 and the visual–spatial sketchpad, and to integrate long-term memory into a unitary episodic representation.

Working memory is often discussed as both a trait- and a state-level variable. This is because at the *trait* level there are individual differences is working memory capacity—some people simply have more working memory resources than others. At the *state* level, various factors can cause a temporary disruption in working memory, reducing the amount of resources available for use at any given time. Because we only have a limited amount of working memory resources available, we must be selective about how we allocate those resources.

Anxiety is thought to affect working memory because the worries that people experience when they are anxious co-opt the working memory resources that would otherwise be allocated to the task at hand (e.g., solving a math task). Thus, when people are anxious, it is as if they are doing two things at once, focusing on their negative thoughts and focusing on their task. This dual-tasking decreases the working memory resources available for the primary task and is what causes us to underperform when we are anxious. This link between anxiety, negative cognitions, and poor performance represents pathway B in Figure 1.

Evidence for the detrimental nature of anxiety-induced thoughts can be seen in Ashcraft and Kirk's pivotal study on math anxiety.[20] Ashcraft and Kirk presented high- and low-math-anxious individuals with addition problems. The questions consisted of 'basic fact' questions in which there were two single-digit operands (e.g., $4+3$) and 'large' questions in which there were two double-digit operands (e.g., $23+11$). Crucial to this study is the belief that 'basic fact' questions can be solved by direct retrieval, meaning that we can bypass the use of working memory resources to solve the problem, whereas correctly solving the 'large' questions requires working memory resources. Furthermore, for half of the questions participants were required to perform a carry operation (making them more working memory demanding). 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. In the more complex (and more working memory demanding) problems in which the addition problem involved carrying, errors increased significantly more for the high-math-anxious individuals than the low-math-anxious individuals. Moreover, this was especially true in the high working memory load condition (i.e., six letters). On carry problems, the high-math-anxious individuals made approximately 40% errors in the high working memory load condition, whereas their low-math-anxious peers made approximately 20% errors. Both the high- and low-math-anxious groups made approximately 10% errors in the low working memory load condition. In other words, both math anxiety groups performed equally well on the simple (and non-working memory demanding questions). Both math anxiety groups also experienced a performance drop on the complex (and working memory demanding) questions relative to their performance on the simple problems. Importantly, the performance drop experienced by the high-math-anxious group was larger than that of the low-math-anxious group. Ashcraft and Kirk interpreted these findings as evidence that the high math anxious individuals, when they are anxious, have a decreased working memory capacity relative to their nonmath anxious peers and thus experience a larger decrement on the working memory demanding (i.e., complex) math questions.[20]

Given that anxiety results in decreased working memory at the state-level, it interacts with trait-level working memory in an interesting way. That is, those who have the largest trait-level working memory capacities actually suffer the most as a function of added pressure and anxiety. Beilock and Carr[4] had people who were naturally low and naturally high in trait-level working memory capacity perform a series of complex math questions first in a no pressure (i.e., low anxiety) condition and then again in a high pressure (i.e., high anxiety) situation. The authors theorized that, independent of who subjectively experiences more anxiety—the low versus high working memory participants—the participants high in working memory may suffer more as a function of their anxiety if they are accustomed to employing math strategies that are highly working memory demanding. The theory was that if high working memory people are relying on their working memory to perform these math tasks more than low working memory people are, then when they experience an anxiety-induced reduction in working memory capacity they will suffer more than their low working memory peers who rely on less effective but less working memory demanding strategies. Beilock and Carr's findings were consistent with this theory. Indeed, the high-working-memory group experienced a greater drop in performance from the no pressure (i.e., low anxiety) to the high pressure (i.e., high anxiety) condition than their peers who were low in trait working memory capacity. A parallel pattern of results has been observed in children with math anxiety. The relation between math anxiety and math performance is negative (meaning that as math anxiety increases, math performance decreases) but the magnitude of this relation is stronger for children who are high in working memory capacity relative to those who are low.[17]

REMEDIATION FOR ANXIETY-INDUCED PERFORMANCE DECREMENTS

In light of the evidence highlighting the detrimental nature of the negative thoughts that arise in stressful situations, several researchers are currently looking to develop remediation techniques to help increase performance by targeting these thoughts. One such intervention involves the use of expressive writing. Researchers asked high-school students, who varied in their levels of test anxiety, to write about their feelings regarding an upcoming exam.[46] The theory was that having the students write about their feelings would help to alleviate the intrusive thoughts that test-anxious students experience and thus would free up their working memory resources for the upcoming test. On the day of the final exam, the researchers asked about half of the students to think about a topic that would not be on their exam for 10 min (the control condition) and asked the other half of the students to write openly about their feelings toward the upcoming exam for 10 min (the expressive writing group). Overall, the expressive writing exercise proved successful as the students who wrote about their feelings had higher overall scores than those who did not write about the upcoming test. Perhaps more importantly, the students with the highest levels of test anxiety benefitted the most from the expressive writing exercise. Indeed, the high test anxious students who engaged in the expressive writing had final exams scores that were as high as the low test anxious students. To test whether the content about which one writes is important or if it is simply the act of writing alone that is enough to boost performance, Ramirez and Beilock conducted a follow-up study in which they asked half of the participants to write about their day (rather than about the upcoming test) and they found no significant benefit of the writing. The authors suggested that the expressive writing may serve to both reduce the frequency of worries and to allow anxious students to reframe the testing situation (i.e., to begin viewing the situation as a challenge rather than as a threat). While the expressive writing technique was first applied to address test anxiety, recent research indicates that it is also effective in increasing math scores in math-anxious students.[23,47]

Another way to alleviate the negative effects of anxiety on performance is to teach anxious students to reappraise their arousal. As we saw previously, viewing a situation as a challenge rather than as a threat can have a strong impact on how one performs.[30] In the work by Lyons and Beilock[39] we saw that some individuals who were high in math anxiety performed well in math despite their anxiety. Lyons and Beilock theorized that these participants may be more likely to be viewing the task as a challenge rather than as a threat. If this is the case, then this represents an example of students naturally reappraising their arousal—that is, assessing the situation and deciding to view it as a challenge rather than as a threat. Given the stark outcome differences between viewing an arousing situation as a challenge rather than as a threat, many researchers are now working to teach students how to reappraise situations when they begin to feel anxious. In one example of this, Jamieson et al.[48] had students take a practice test in the lab for an upcoming high-stakes test. Half of the students were told that arousal helped with performance (the reappraisal condition) while the other half were 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.

One area in which much research has investigated the value of reappraisal on performance is the field of stereotype threat. Stereotype threat refers to the fear of acting in such a way that confirms a negative stereotype about a group to which one belongs.[49]

For example, women will often underperform on math tests if they are reminded of the stereotype that women are not as good as men in math before taking the test. Stereotype threat is thought to negatively impact cognitively demanding tasks much the same way that anxiety does—via negative thoughts and ruminations that tie up working memory resources (for a review on similarities between stereotype threat and math anxiety see Ref 50). Johns et al.[51] were able to eliminate the effect of stereotype threat by teaching women about the phenomenon and the anxiety that it might produce. They had men and women complete difficult math problems that were described either as a problem-solving task (the control group) or as a math test (the stereotype threat group). A third group was also told that the task was a math test (a stereotype induction), but participants in this third group 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 math 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 one mechanism by which anxiety and stereotype threat impact performance (i.e., negative thoughts and ruminations tying up working memory resources) is the same, the above-mentioned reappraisal interventions hold promise for reducing the negative impact of both math anxiety and test anxiety on performance.

Although reappraisal targets the cognitive consequences of anxiety, other techniques are being investigated that aim to reduce the maladaptive patterns of physiological arousal that result from anxiety. For example, breathing techniques have been shown to have excellent prospects for reducing the negative consequences of anxiety. Indeed, participants with high math anxiety who were given a focused breathing exercise prior to a math task had a greater increase in math performance when compared to their counterparts who received either an unstructured breathing exercise, or an exercise meant to exacerbate their worries.[52] It may be the case that breathing exercises act as a way to alter maladaptive heart rate responses and train attention skills, essentially freeing cognitive resources to be used for another given task.[5]

Taken together, these various approaches to reducing the negative impact of anxiety on performance, whether by using expressive writing, reappraisal, or breathing centered training, provide us with a sense of optimism that although experiencing anxiety is very common among our students, it need not be a reason for them to underperform. Each of the interventions discussed here also have the advantage that they are relatively easy to implement and can be effective with only a short training session suggesting that it may be beneficial to train educators to use these techniques in the classroom.

In addition to designing interventions intended to reduce the negative impact of anxiety on performance, another approach is to prevent the development of math anxiety and test anxiety all together. This is, of course, challenging as we are still uncovering the antecedents to these anxieties but recent research is suggesting promising starting points. Take, for example, math anxiety. Research by Maloney et al. suggests that math anxiety may stem, in part, from difficulties with the very building blocks of math (i.e., number representation and spatial abilities[24–26]). Against this background, it may be helpful to design programs aimed at bolstering number sense and spatial ability in the children who are most at risk of developing math anxiety.

In other research with math anxiety, Beilock et al.[24] demonstrate a link between a teacher's level of math anxiety and her students' math gender beliefs and math achievement. This link is particularly unnerving given that early education majors have the highest levels of math anxiety of all college majors.[17] This finding suggests that one key to preventing the development of math anxiety in young children may be to target pre-service teachers. Designing interventions that aim to eliminate math anxiety in these teachers before they ever enter the classroom to teach may go a long way in preventing the development of math anxiety in many young children.

CONCLUSION

Although we need some arousal to perform at our best, too much arousal, if it is interpreted as a threat rather than as a challenge, leads to anxiety and subsequent physiological and cognitive changes that disrupt performance. Interestingly, research into various types of anxiety (e.g., test anxiety, math anxiety) suggests that, although anxiety can arise for different reasons, the mechanisms by which it disrupts performance are the same. Namely, anxiety causes changes in our physiology as well as negative thoughts and ruminations that co-opt valuable working memory resources needed to succeed on cognitively demanding tasks. Here, we demonstrated that anxiety can lead to underachieving in cognitive tasks by the two pathways seen in Figure 1: (A) anxiety causes physiological changes and regulation of these physiological changes require the same neural resources as cognitive tasks, and (B) anxiety can lead to negative thoughts and ruminations which occupy working memory resources that would otherwise be used for the task.

One advantage to the fact that various anxieties seem to affect performance via similar mechanisms is that interventions shown to help reduce the impact of one type of anxiety on performance should, in theory, work for all (or at least most) types of anxiety. Given the growing body of research demonstrating promising interventions, it seems safe to postulate that decreasing the widespread phenomena of students performing suboptimally as a function of their anxiety is well within our reach.

NOTES

[a] Evidence consistent with this claim comes from recent research[29] linking prefrontal cortical control to parasympathetic regulation of heart rate by using positron emission tomography (PET) to measure changes in regional cerebral blood flow while also measuring heart rate. It was found that decreased blood flow to the dorsolateral prefrontal cortex (DLPFC) was linked to an increase in heart rate and a decrease in the variability of heart rate.

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