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The math anxiety-math performance link and its relation to individual and environmental factors: a review of current behavioral and psychophysiological research

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Anxiety about mathematics — highly prevalent across the globe — is associated with poor math performance. Why is math anxiety related to poor math performance and how can we reduce this link? Current behavioral and psychophysiological research reveals that the math anxiety-math performance link is related to both individual (cognitive, affective/physiological, motivational) and environmental (social/contextual) factors. Several interventions have recently been developed to alleviate the relation between math anxiety and math performance. To lower math anxiety and reduce its relation to poor math performance, future interventions may benefit from focusing on both math-anxious individuals themselves and those around them.

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Math anxiety: definition, prevalence and consequences

Math anxiety is defined as 'a feeling of tension, apprehension, or fear that interferes with math performance' [1]. While sharing some common features with other types of anxiety, math anxiety is a separate phenomenon from general trait anxiety or test anxiety [2,3] and is associated with specific impairments in processing math-related or number-related tasks [4,5•,6•,7••]. Math anxiety is a global phenomenon and is highly prevalent: on average across 65 countries and economies that participated in 2012 Programme for International Student Assessment (PISA), 33% of 15-year-old students report feeling helpless when solving math problems [8]. In the U.S., an estimated 25% of four-year college students and up to 80% of community college students suffer from a moderate to high degree of math anxiety (DS Yeager, paper presented at the annual meeting for the American Educational Research Association, Vancouver, BC, Canada 2012).

Math anxiety often results in avoidance of math and math-related situations altogether [9]. Its negative consequences may include: poor performance on standardized math tests and general difficulty with math-related problem-solving [2]; low performance on courses involving numerical reasoning [10•]; reduced efficiency in solving simple arithmetic problems [11]; or difficulties in basic numerical processing [12,13]. Further exacerbating these adverse effects is the possibility of a reciprocal relation between math anxiety and math performance: as math anxiety interferes with math performance [14], poor math performance could in turn increase one's math anxiety [15].

In general, higher levels of math anxiety are associated with lower math performance. Although math anxiety may not be the only variable related to math performance, it is indeed a strong predictor. Across OECD countries, 14% of the variation in math performance is explained by variation in math anxiety, and among the highest achieving students, this relationship remains strong even when controlling for gender and socioeconomic status [8]. Given the high prevalence of math anxiety and its significant negative relation to math proficiency, understanding the factors that explain the relation between math anxiety and math performance may provide valuable insights for boosting math achievement.

This review explores current behavioral and psychophysiological work attempting to clarify the mechanisms underlying the relation between math anxiety and math performance, and introduces select interventions found to be beneficial in reducing math anxiety or disrupting the negative relation between math anxiety and math performance — at levels of an individual as well as the environment. While past work has mostly studied the math anxiety-math performance relation at the level of an individual, recent findings indicate that math anxiety may also operate at a broader contextual level — across students, parents, and teachers. By reviewing current evidence on individual and environmental factors accounting for the math anxiety-math performance relation and on how to reduce this link, we supplement reviews on a related topic (see [16] for a comprehensive overview of

past literature on math anxiety and [17] for a review of causal relation between math anxiety and math performance) and provide additional insights for future directions related to the math anxiety phenomenon.

Math anxiety and math performance: possible factors that explain the relation

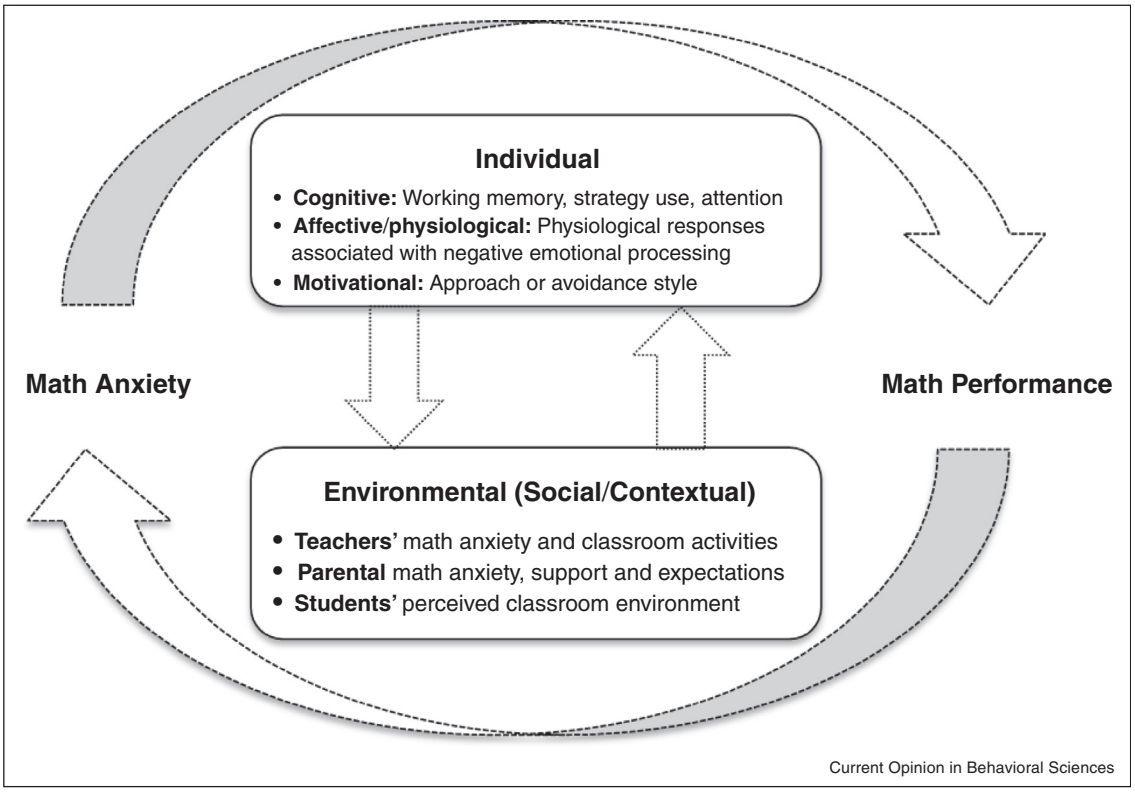
One explanation for the negative relation between math anxiety and math performance is that math-anxious individuals are less competent at math than their non-math-anxious counterparts [18]. That is, math anxiety is simply a proxy for poor math performance. Indeed, math anxiety is associated with difficulties in basic numerical processing, which is thought to form the building blocks of more advanced math skills [12,13]. Recent psychophysiological work demonstrates that high-math-anxious individuals (HMAs) exhibit reduced event-related potential (ERP) amplitude in the early stages of numerical processing [19•], greater numerical distance and size effects, and a larger amplitude of ERP distance effect [20•]. Therefore, poor math performance associated with math anxiety could, in part, stem from less precise understanding of numerical magnitudes.

However, past and current research suggests that not all math-anxious individuals do poorly on math. There seem to be various factors beyond simple differences in math problem solving skills that account for the negative relation between math anxiety and math performance. Behavioral and psychophysiological work provide converging evidence for individual (cognitive, affective/physiological, motivational) and environmental (social/contextual) factors that may explain the math performance gap between students with high and low levels of math anxiety, as outlined in Figure 1.

Individual

Cognitive. Working memory is a limited short-term memory system that enables one to attend to the relevant task at hand while inhibiting irrelevant information (see [21]). Math-anxious individuals perform poorly on math tasks that rely substantially on working memory, such as addition that involves carrying, but do not show decrements when the problems can be solved via simple fact retrieval [14]. Consequently, it is hypothesized that worries and intrusive thoughts associated with math anxiety reduce working memory resources needed for cognitively demanding math tasks. In support of this hypothesis, recent neuroimaging work shows that math performance decrements among HMAs vary depending on how much they ramp up cognitive control resources (activity in the frontoparietal network including inferior frontal junction) at the prospect of doing math [4]. Accordingly, poor math performance in some HMAs may be due to anxiety-related depletion

Figure 1



Multiple individual and environmental factors account for the reciprocal relation between math anxiety and math performance.

of cognitive resources, and such effects may dissipate among individuals who, by recruiting brain regions associated with cognitive control, successfully reappraise their negative emotions prior to math performance.

It is also important to point out that working memory capacity differs across individuals: some individuals have more capacity and others have less. Higher working memory individuals may be more likely negatively affected by anxiety that co-opts working memory they would otherwise use to carry out difficult math tasks. Indeed, the negative relation between math anxiety and math achievement is the strongest among students with high working memory [22•]. Additionally, in children with high working memory capacity, math anxiety negatively relates to math achievement via a reduction in reliance on retrieval-based strategies (considered working-memory-demanding for young children; [23•]), suggesting that anxiety impacts high-working-memory individuals' use of working-memory-intensive strategies. This finding that the use of retrieval strategy mediates the negative math anxiety-math performance relation is consistent with past research showing that math-anxious children have a higher threshold to select retrieval-based strategies, and the reduced frequency in retrieval-based strategy use is associated with poor math performance [11]. Increased anxiety-related online interference among those with higher working memory may persist while learning new math knowledge [24•]. Taken together, the negative relation between math anxiety and math performance and learning may be more pronounced for students who have the highest potential to perform on math tasks.

Recent work also points to the possibility that impaired attentional mechanisms could reduce the efficiency in mathematical problem solving — even for the simplest math problems that HMAs may not explicitly feel anxious about — due to attentional bias toward math-related stimuli [5•,25•], impaired attentional control and enhanced susceptibility to distractions [6•,26•,27•,28•], or elevated inhibition of anxiety-related responses [7••]. For example, compared to low-math-anxious (LMA) counterparts, HMAs are slower at identifying the colors of the math-related (compared to neutral) words in an emotional Stroop task, reflective of preferential allocation of attentional resources to math-related stimuli [25•]. HMAs respond faster when the probe and numerical prime are presented in the same location (compared to when they are shown in different locations) in a dot-probe task, indicating increased selective attention toward (and possibly difficulty in disengaging from) numerical stimuli [5•]. These findings suggest that math-anxious individuals may perceive math-related stimuli as threatening, and thus may be more inclined to attend to them, impairing their ability to allocate their attention to relevant aspects of the task at hand.

Affective/physiological. In general, anxiety is associated with various affective and physiological responses. High levels of math anxiety are known to be associated with increased cardiovascular activity (Faust, PhD thesis, Bowling Green State University, 1992), increased salivary cortisol concentration predicting poor math performance (within high-working-memory individuals; [29]), and increased activation in brain regions associated with pain perception [30] and negative emotional processing [31].

When anticipating a math task, HMAs exhibit increased activation in neural areas associated with pain-related responses (e.g. dorso-posterior insula), possibly indicating that these individuals may even feel visceral pain when simply thinking about math [30]. Fear-related and anxiety-related physiological responses associated with math anxiety have been shown early in development: second and third grade children who report being highly math-anxious show increased negative emotional processing (as indexed by hyperactivity in right amygdala) during math performance [31].

Motivation. Math motivation, by enhancing approach style and diminishing avoidance style, may be important in how math anxiety affects math performance. Individuals who are highly motivated may overcome their negative responses associated with math anxiety by actively approaching the math task at hand. On the other hand, those who are less motivated may have a greater tendency to avoid the math-related situations that evoke anxiety. Until recently, few studies have examined math motivation as a factor that may influence the math anxiety-math performance relation.

Wang *et al.* [32•] show that intrinsic math motivation moderates the patterns of relation between math anxiety and math performance. Children and adults with high levels of intrinsic motivation show a curvilinear (inverted-U) relation: moderate levels of math anxiety are associated with better performance, compared to extremely low and high levels of math anxiety. On the other hand, those with low math motivation show a linear, negative relation between math anxiety and math performance. These findings indicate that math anxiety may not uniformly impact math performance across individuals varying in motivation. Given that the patterns of relation between math anxiety and math performance may vary as a function of how individuals approach math-related situations, future work should take such math motivation into consideration.

Environmental (social/contextual)

Social and contextual factors are crucial in explaining how math anxiety develops and how it relates to math performance [33•]. Teachers' math anxiety and classroom activities [34], parental math anxiety, support and expectations [35•,36•], and students' perceived classroom environment

[37] are non-negligible social or contextual factors that may affect the math anxiety-math performance relation.

Teachers and parents. Teachers and parents are role models for children — their attitudes toward, and ability to teach, math may indirectly influence the students' levels of math anxiety and their math performance. For instance, female teachers may transmit their math anxiety to their female students by endorsing stereotypes about gender and math, which reduces students' math performance [34]. Parental involvement of math-related activities and expectations are also influential. Among low-income minority second graders, parental home support and expectations influence their child's performance on word problems and algebraic reasoning by reducing the child's math anxiety [35•]. The benefits of home support may, however, inadvertently backfire if parents are highly math-anxious. First and second grade students' parents' math anxiety is associated with reduced growth in math achievement and increased math anxiety among students across the school year, when their parents report frequently helping with students' math homework [36•].

Students. Students' perceived classroom environment plays an important role in students' math performance. Fourth–sixth grade students who perceive their classroom as more caring, challenging, and mastery-oriented have higher levels of math self-efficacy, and in turn, higher math performance [37]. While future studies may benefit from including a math anxiety measure to establish the link between perceived classroom environment and math anxiety, current research suggests that math self-efficacy (the degree to which the student believes he or she is capable of performing on math) is significantly related to math anxiety. For example, in second grade students, lower math self-efficacy predicts higher levels of math anxiety [38•]. Taken together, various social and contextual factors appear to contribute to the development of math anxiety. Many of these factors also reinforce the relation between math anxiety and math performance.

Interventions that reduce math anxiety-related math performance decrements

Interventions targeting the high math-anxious individuals as well as their environment are shown to be effective. At the level of an individual, practicing a computer adaptive math program [39•], reappraising pre-performance anxiety [40•,41•], practicing a focused breathing exercise [42•], stimulating neural circuits involved in cognitive control [43•], cognitive behavior group therapy [44], relaxation training [45], acceptance and commitment therapy and systematic desensitization [46], and listening to sedative music [47•] are shown to improve math performance or reduce math anxiety. At the level of the environment, increasing math exposure through one-on-one math tutoring [48••] and increasing math activities at home [49•] are shown to improve math performance among high math-anxious individuals.

In line with the possibility that math anxiety is both directly and indirectly related to math performance, interventions aimed at alleviating math anxiety, training math skills, or remediating other factors that influence this relation seem to be beneficial in boosting math-anxious individuals' math performance. It remains an empirical question which methods are the most effective and long-lasting. Furthermore, considering that math anxiety shares some common features with other types of anxiety, interventions known to be successful for other types of anxiety, such as reappraisal [50], mindfulness [51], or exposure therapy [52], may also be beneficial in reducing math anxiety and demand empirical attention.

Conclusions

As summarized in Figure 1, the current review examined various factors that may account for the math anxiety-math performance relation — at levels of an individual and the environment. The mutually reinforcing relation between math anxiety and math performance highlights the need for reducing this link. Interventions aimed at alleviating math anxiety, training math skills, or remediating other factors that influence this relation — targeting individuals and the environment — have been developed to improve math performance in highly math-anxious individuals.

Future studies may enhance our understanding of math anxiety-math performance association by identifying various contextual factors that mediate or moderate this relation and may also develop effective interventions by targeting highly math-anxious individuals as well as their parents and teachers. Further, multiple levels of analysis across genetic, psychophysiological, behavioral, and self-report assessments across populations with diverse sociocultural backgrounds are needed to delineate the specificity of math anxiety and the extent to which it is associated with math performance. Lastly, development of longitudinal studies would be critical in understanding the ontogeny of math anxiety, how it affects math performance across development, the nature of the (causal) link between math anxiety-math performance, and what kinds of interventions may be the most beneficial in the long run.

Conflict of interest statement

Nothing declared.

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