



# A Framework for Studying the Heterogeneity of Risk Factors in Math Anxiety

Orly Rubinsten<sup>1,2\*</sup>, Hadas Marciano<sup>3,4</sup>, Hili Eidlin Levy<sup>1,2</sup> and Lital Daches Cohen<sup>1,2</sup>

<sup>1</sup>Edmond J. Safra Brain Research Center for the Study of Learning Disabilities, University of Haifa, Haifa, Israel, <sup>2</sup>Department of Learning Disabilities, University of Haifa, Haifa, Israel, <sup>3</sup>Department of Psychology, Tel Hai College, Kiryat-Shmona, Israel, <sup>4</sup>Ergonomics and Human Factors Unit, University of Haifa, Haifa, Israel

Math anxiety is a prevalent disorder which affects many people worldwide. Here, we draw together ample evidence to suggest a dynamic developmental bio-psycho-social model. The model highlights the complex pathways towards the development of math anxiety, with a focus on dynamism. That is, math anxiety is viewed here as a dynamic interplay between environmental (parenting style, as well as social style including teachers' attitude, instruction strategies and wider social effects) and intrinsic factors (i.e., neuro-cognitive and genetic predispositions, including brain malfunctions, heritability, predisposition towards general anxiety) and basic numerical cognition and affective factors. The model predicts that the dynamic interplay between these factors can either prevent or promote math anxiety's effects on the development of heterogeneous symptoms. Considering the universal nature of math anxiety, a systematic description of the vulnerability factors that contribute to the development of math anxiety is vital. Such information may be of particular value in informing the design of preventive interventions as well as of specific intervention tools.

**Keywords:** math anxiety, risk factors, framework, dynamic perspective, heterogeneity

Math anxiety (Richardson and Suinn, 1972) comprises heterogeneous manifestations of symptoms (see **Figure 1**), including a negative attitude towards mathematics (Gierl and Bisanz, 1995; Dowker et al., 2012), feelings of stress in situations involving numerical information and avoiding activities which include numbers or quantities. High math anxiety levels are also associated with inflated physiological arousal during math related situations, such as taking a math test (e.g., Dreger and Aiken, 1957; Pletzer et al., 2010). Furthermore, math anxiety has consistently been shown to be negatively related to math achievement (e.g., Wigfield and Meece, 1988; Hembree, 1990; Ma, 1999). In the long run, math-anxious individuals are less likely to have math-related careers (science, technology, or engineering; see Hembree, 1990; Ma and Xu, 2004a,b; Ashcraft and Ridley, 2005; Maloney and Beilock, 2012). Math anxiety has been associated with increased health costs (Woloshin et al., 2001; Parsons and Bynner, 2005; Duncan et al., 2007; Reyna et al., 2009), low socioeconomic status (Ritchie and Bates, 2013) and mortgage default (Gerardi et al., 2013). In Western society poor numeracy is seen as a greater handicap than poor literacy (Rivera-Batiz, 1992; Estrada et al., 2004).

While understanding of the risk factors of math anxiety (Maloney and Beilock, 2012; Dowker et al., 2016; Suárez-Pellicioni et al., 2016) and its remediation (Supekar et al., 2015)

## OPEN ACCESS

### Edited by:

Richard G. Hunter,  
University of Massachusetts Boston,  
United States

### Reviewed by:

Delphine Sasanguie,  
KU Leuven Kulak, Belgium  
Ann Dowker,  
University of Oxford, United Kingdom

### \*Correspondence:

Orly Rubinsten  
orly.rubinsten@gmail.com

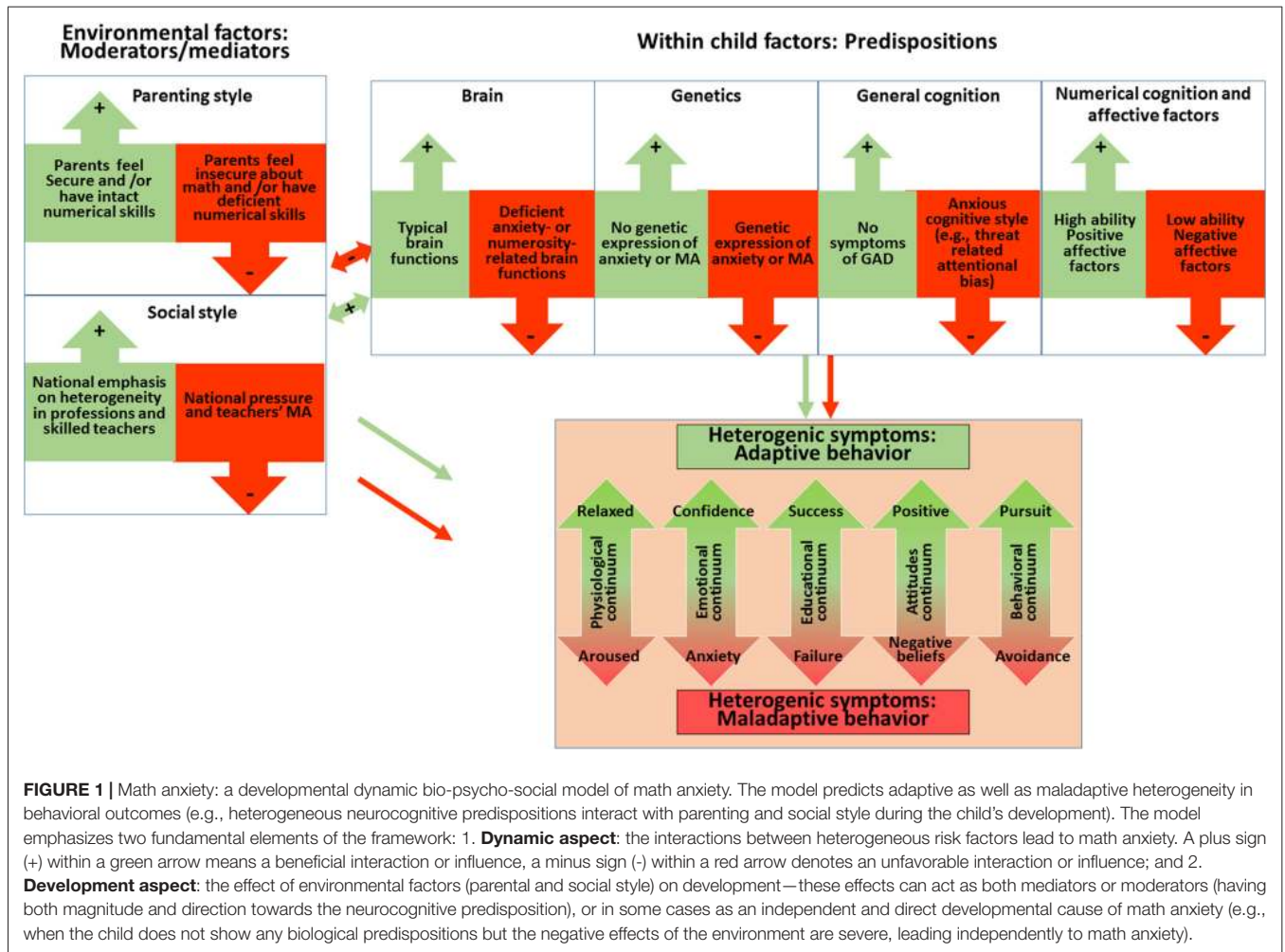
**Received:** 26 July 2018

**Accepted:** 12 November 2018

**Published:** 03 December 2018

### Citation:

Rubinsten O, Marciano H,  
Eidlin Levy H and Daches Cohen L  
(2018) A Framework for Studying the  
Heterogeneity of Risk Factors in Math  
Anxiety.  
*Front. Behav. Neurosci.* 12:291.  
doi: 10.3389/fnbeh.2018.00291



has progressed, the question of why one person develops math anxiety while another does not, remains unresolved. Such understanding will enable new intervention programs to reduce the prevalence of math anxiety, which will address the range of possible antecedents of math anxiety rather than focusing solely on numerical skills (e.g., Supekar et al., 2015). Moreover, awareness of the entire spectrum of heterogeneous antecedents, may enable early identification of students who are at risk of developing math anxiety.

Indeed, a wealth of empirical evidence provides insights regarding distinct aspects of math anxiety (e.g., Daches Cohen and Rubinsten, 2017), including intervention studies on different features that are involved in its onset (e.g., Supekar et al., 2015) and systematic experimental studies with clinical populations (e.g., Lyons and Beilock, 2011) that target putative causal factors.

Here, we aim to assemble a range of data with relevance for issues of etiology, and to suggest a framework that organizes the entire spectrum of risk factors, for the study of math anxiety. This framework is concerned with the underlying mechanisms by which a variety of potential causes lead to math anxiety. The major assumptions of the current model

are that mechanisms for math anxiety depend upon: (1) the interaction and dynamics between risk factors; and (2) changes in risk factors during human development. Thus, math anxiety is viewed here within the framework of a dynamic developmental perspective.

Although it is currently unfeasible to fully describe the origins and outcomes of math anxiety, we present an initial model focusing on the development and dynamic interplay between causal factors. Continuing previous important reviews of the antecedents of math anxiety and its developmental trajectory (e.g., Maloney and Beilock, 2012; Beilock and Maloney, 2015; Dowker et al., 2016), our current model highlights and visually illustrates dynamic and developmental perspectives claiming that heterogeneous symptoms of math anxiety result from the interplay between individual predispositions and one's surroundings. The model predicts that the exact math anxiety symptoms at a particular time in life will be affected by factors that have positive or negative effects on the development of symptoms. The actual heterogeneous symptoms manifested are therefore a result of all of these different forces. Note that despite the importance of both antecedents and symptoms, and based on Sagvolden et al. (2005) the current article focuses on

the heterogeneity and dynamics of the causes (i.e., risk factors) of math anxiety. Such a dynamic developmental model may open the door for future research to better understand the onset of math anxiety and to promote more comprehensive models.

## DEVELOPMENTAL PERSPECTIVE

There is currently insufficient evidence to determine whether the below mentioned factors (e.g., threat related attentional bias) are a cause or effect of math anxiety. However, longitudinal studies are beginning to examine these complex relationships. Recent studies have shown that the accumulation of negative experiences with learnt numerical information leads to math anxiety (Cargnelutti et al., 2017; Gunderson et al., 2018), emphasizing the importance of a developmental perspective. However, few studies have delineated developmental trajectories of the symptomatology of math anxiety and suggested moderate stability in the symptoms throughout middle childhood, especially for low math achievers. Specifically, a longitudinal study found that low scholastic achievers reported higher and stable math anxiety levels over time compared to high achievers who showed a higher anxiety level at the beginning and the end of the school year, which after an adjustment period reverted to its lower level, suggesting susceptibility to changes over time (Madjar et al., 2016). Indeed, there are known accounts of math anxious people during childhood who later overcame their anxiety to become proficient mathematicians and even Fields Medal winners (considered the mathematician's "Nobel Prize"), such as Prof. Laurent Schwartz who wrote in his autobiography: "...towards the end of the eleventh grade, I secretly thought of myself as stupid. I worried about this for a long time" (Schwartz, 2001). Similarly, Prof. Maryam Mirzakhani, the first woman to win the Fields Medal, had a middle school math teacher who thought that she was not talented, which undermined Mirzakhani's confidence<sup>1</sup>.

Thus, our model suggests heterogeneity in the continuity and manifestations of the math anxiety disorder, with expressions of math anxiety symptoms varying at different developmental phases, due to the dynamic interplay between environmental and intrinsic factors.

## THE DYNAMIC PERSPECTIVE AND A GENERAL DESCRIPTION OF THE MODEL

The model comprises a dynamic bio-psycho-social perspective describing how individual variations in competing factors of neuro-cognitive and genetic predispositions (*within-child*), together with parenting style and social style (*environmental factors*), may affect math learning processes and emotional functions, thereby producing heterogeneity within math anxiety (Figure 1). These factors can either interact or cancel each other during development. Environmental factors refer to the feelings and actions of parents, teachers and other formal

agents of society, regarding mathematics. While some of them feel secure about their own math abilities and transfer their secure feelings to the child, others suffer themselves from math anxiety or math difficulties and may project these maladaptive patterns to the child (Beilock et al., 2010). Environmental risk factors for math anxiety can be found in school (Beilock et al., 2010; Gunderson et al., 2012), during extra-curricular activities (Berkowitz et al., 2015), and within the child's family (Berkowitz et al., 2015; Maloney et al., 2015; Daches Cohen and Rubinsten, 2017; for protective parental effects see Gunderson et al., 2018).

The *within-child* factor refers to the child's predispositions, related either to *neural correlates*, the child's *genetics*, the child's tendency toward *anxiety in general* (Generalized Anxiety Disorder, GAD), or *basic numerical skills and affective factors*. Specific neural correlates can involve, for example, mathematics-related brain dysfunction in the intraparietal sulcus, that increase the probability of exhibiting math anxiety (Young et al., 2012). *Genetic heritage* refers to the genetic root of math anxiety, found mostly through studies of twins (Wang et al., 2014; Malanchini et al., 2017). The question regarding *basic numerical cognition and affective factors* seeks to determine whether deficient numerical skills lead to math anxiety (e.g., Ma and Xu, 2004a) or rather math anxiety leads to deficient mathematical performance (e.g., Ashcraft and Kirk, 2001; Maloney and Beilock, 2012; Park et al., 2014). The *tendency toward GAD* suggests that children predisposed to GAD (Hembree, 1990; Ashcraft and Moore, 2009; O'Leary et al., 2017), including maladaptive threat related attentional bias (excessive attention to threat stimuli, Bar-Haim et al., 2007; Bishop, 2009; Cisler and Koster, 2010; Luijten et al., 2012), are at greater risk of developing math anxiety. All of these within-child factors affect how the individual interprets communication signals from the environment (e.g., Chorpita et al., 1996; Dineen and Hadwin, 2004; Affrunti and Ginsburg, 2012).

The model indicates that even if one or more of these predispositions exists, math anxiety will not necessarily develop. Other environmental factors, serving as mediator or moderator variables, including parenting and/or social style, may help the child "overcome" the deficits, generating adaptive behavior.

Importantly, the link between environmental and within-child factors (pre-dispositions) is bidirectional. This perspective expands other models that aim to identify the factors that individually and collectively account for large amounts of variance in math and science achievement, such as the Opportunity-Propensity (O-P) Model (Byrnes and Miller, 2007; Byrnes and Wasik, 2009; Baten and Desoete, 2018). The O-P model assumes that distal factors (e.g., socioeconomic status) predict the proximal factors, which include opportunity factors (e.g., coursework) and propensity factors (e.g., prerequisite skills). These proximal factors, in turn, predict the developmental outcomes.

In contrast, in the current model children are not passively influenced by their teachers, parents and the larger culture. Rather, we emphasize a bi-directional link in which environmental factors can be influenced by characteristics

<sup>1</sup>Taken from <https://www.wired.com/2014/08/maryam-mirzakhani-fields-medal/>

of the student, which in turn may influence the student's math anxiety. Indeed, research shows that individuals can be dynamic producers of their environment (e.g., Lerner, 2001; Heckhausen et al., 2010; Lerner and Busch-Rossnagel, 2013). Namely, individuals can actively change their environment by, for example, extracting different responses from others, or by understanding and interpreting communications in distinctive ways (Dineen and Hadwin, 2004).

Hence, as can be seen in **Figure 1** and as elaborated below, environmental factors can act as moderators that reduce the effect of pre-dispositions on the development of math anxiety, but they can also act as mediators and affect the pre-dispositions themselves. Similarly, either innate (i.e., pre-disposition) or learnt (environment) numerical skills are suggested to have a reciprocal relationship with math anxiety.

Note that the *within-child* factors are seen as predispositions for MA, while environmental factors may act as either mediators or moderators. Therefore, in what follows, they will be described first. However, it should be stressed that these predispositions are not mandatory or necessary in order to develop math anxiety, because the other (environmental) factors, either alone or together, may act as an independent direct developmental cause of math anxiety. Thus, the actual severity and specific symptoms of math anxiety (see the bottom of **Figure 1**) are heterogeneous and depend on the dynamic pattern between all of the following risk factors.

## WITHIN-CHILD FACTORS: BIOLOGICAL PREDISPOSITIONS

### Genetic Predisposition

*Genetic* studies may reveal whether genetic predisposition does in fact emerge first to cause math anxiety development. A recent study on monozygotic vs. same-sex dizygotic teenage twins found that genetic factors accounted for about 40% of the math anxiety variance and that 9% of the total variance in math anxiety resulted from genes related to GAD (Wang et al., 2014). Similar results were found with older twins (Malanchini et al., 2017), suggesting that some of the origins of math anxiety rely on genetic factors. According to Dowker et al. (2016), it is reasonable to assume that no genetics factors are specific to math anxiety. Indeed, in a multivariate analysis (Wang et al., 2014), math anxiety was influenced by the genetic and nonfamilial environmental risk factors involved in general anxiety and the genetic factors were associated with math-based problem solving. Therefore, math anxiety may result from a combination of negative experiences with math and genetic predisposition associated with both math cognition and general anxiety.

### Neural Predisposition

Neuronal correlates of math anxiety have been linked to different brain activation patterns (Artemenko et al., 2015), which relate to affective or cognitive mechanisms. In one study (Young et al., 2012) children with math anxiety exhibited reduced activity in the posterior parietal and dorsolateral prefrontal cortex (DLPFC) regions (known to be involved in

mathematical reasoning), on the one hand, and higher and abnormal effective connectivity between the amygdala and ventromedial PFC regions that regulate negative emotions, such as fear, on the other. Specifically, among the high math-anxious children, the amygdala showed greater coupling with cortical regions involved in processing and regulating negative emotions, whereas in their low math-anxious peers, the amygdala was coupled with brain areas that facilitate efficient task processing.

Others (Lyons and Beilock, 2012) found increased activation in the pain perception network, including the bilateral dorso-posterior insula and mid-cingulate cortex, among high math-anxious individuals who anticipated a math task. Interestingly, these areas showed no significant activation during completion of the task. It seems that before engaging in math tasks, math anxious individuals show pain-related activity, while during the actual math engagement they show fear-related neural activity (Artemenko et al., 2015). Similarly, high math-anxious individuals demonstrated greater involvement of the right insula for numeric than for nonnumeric errors (Suárez-Pellicioni et al., 2013a), a brain structure that has been associated with pain (Isnard et al., 2011), emotional processing (Phan et al., 2002) and anxiety disorders (Paulus and Stein, 2006). These results may explain the avoidance behavior that characterizes math-anxious individuals (Hembree, 1990; Ashcraft and Ridley, 2005).

Importantly, while anticipating a math task, increased activation in the frontoparietal network, which is known to be involved in regulating negative emotions (including the inferior frontal junction, the inferior parietal lobule and the left inferior frontal gyrus), predicted activation of the right caudate nucleus and the left hippocampus when performing a math task among high math-anxious individuals. These two subcortical regions are necessary for coordinating task demands and motivational factors (Lyons and Beilock, 2012). Thus, activation of brain substrates of the cognitive control function when anticipating a math task can mitigate the effects of math anxiety on performance. In this line of research, high math-anxious individuals demonstrated reduced activity in the DLPFC, a brain region which is also thought to be involved in cognitive control (Young et al., 2012). Moreover, transcranial direct current stimulation (tDCS) to the DLPFC improves the performance of high math-anxious individuals and even ameliorates their anxious response, as reflected in declines in cortisol concentrations (Sarkar et al., 2014).

Nevertheless, it is not clear whether these neural patterns are a cause (predisposition) or effect of math anxiety, a question that remains to be resolved by future longitudinal studies (e.g., Luo et al., 2011). Furthermore, the reported brain activation patterns can also reflect individual differences, as well as cognitive strategy differences. For example, increased math anxiety levels were associated with low math achievements, as well as with reduction of gray matter volume in the left anterior intraparietal sulcus, a region associated with attention processing (Hartwright et al., 2018). Concurrent with the attentional control theory (Eysenck et al., 2007), the authors hypothesized that



both increased math anxiety and limited attentional resources may reduce math achievements by depleting working memory capacity.

### Cognitive and Neuro-Physiological Predisposition: The Link With Generalized Anxiety Disorder (GAD)

The neural component of math anxiety is further demonstrated in studies showing a correlation between GAD and math anxiety (Hembree, 1990; Wang et al., 2014; Malanchini et al., 2017). Our model claims that sometimes math anxiety is linked, at least during initial development, to symptoms of GAD. Intrinsically vulnerable people tend to hold cognitive traits of anxiety (e.g., maladaptive threat-related attentional bias), as well as maladaptive neuro-physiological responses, which can constitute an independent risk factor for math anxiety. Indeed, general-anxiety related **neuro-physiological responses** and increased negative emotional processing have been found in young children with math anxiety, as indicated by hyperactivity in the right amygdala during math performance (e.g., Cargnelutti et al., 2017). Currently, there is insufficient evidence to conclude whether GAD acts as a predisposition in cases of math anxiety. However, longitudinal studies are beginning to examine these relationships. For example, in a longitudinal path model, GAD was found to be a significant predictor of math achievements, stronger in second than in third grade (Cargnelutti et al., 2017).

A leading theory explaining **the cognitive aspects** of math anxiety suggests that individuals with math anxiety do not necessarily suffer from math learning disabilities (Ashcraft and Kirk, 2001; Ashcraft et al., 2007). Rather, they suffer from typical GAD symptoms, specifically math anxiety-induced ruminations (repetitive thinking about negative personal concerns, Nolen-Hoeksema et al., 2008). These ruminations jeopardize cognitive resources such as working memory. As a consequence, insufficient cognitive resources lead to lower performance on numerical tasks (Beilock, 2010; Maloney and Beilock, 2012; Ramirez et al., 2016). However, note that others have suggested a bidirectional link between math anxiety and math performance, meaning that math anxiety can be simultaneously both the cause and consequence of math difficulties (Carey et al., 2016), as will be detailed below.

Against this background, we argue that some of the cognitive traits associated with GAD, such as attentional bias toward negative information (Muris et al., 2003; Ashcraft and Moore, 2009) which leads to anxiety-induced ruminations, are also involved in math anxiety. Though selective attention to threat reflects the adaptive neurocognitive function of protection from danger (Bar-Haim et al., 2007, 2010; Robinson et al., 2012), dysfunction in this process results in threat-related attentional bias (Bar-Haim et al., 2007, 2010; Ashcraft and Moore, 2009; Bishop, 2009; Van Bockstaele et al., 2014; O'Leary et al., 2017). Indeed, we and others (Rubinsten et al., 2015; Suárez-Pellicioni et al., 2015) have shown maladaptive threat-related attentional bias towards basic numerical information in adults with math anxiety. This finding suggests that math anxiety results from maladaptive characteristics of

GAD that lead to experiencing the world, and mainly the parts associated during development with negative valence (e.g., numerical information), as threatening. Attentional bias toward threat-related stimuli, in turn, interfere with attentional control and increase sensitivity to distractions (Suárez-Pellicioni et al., 2013b, 2014) or to the inhibition of anxiety-related responses (Pletzer et al., 2015). Therefore, if a child with GAD encounters adverse numerically-related pedagogical or social events, the risk of developing math anxiety increases.

### Numerical Cognition and Affective Factors

Math anxiety has consistently been shown to be negatively related to math achievement (e.g., Wigfield and Meece, 1988; Hembree, 1990; Ma, 1999). As an example, math anxiety have been found to be associated with basic numerical skills, such as simple counting (Maloney et al., 2010; Rubinsten and Tannock, 2010; Rubinsten et al., 2012; Núñez-Peña and Suárez-Pellicioni, 2014). In addition, children with diagnosed mathematical disabilities exhibited more math anxiety compared to a control group (Rubinsten and Tannock, 2010; Passolunghi, 2011). Furthermore, it has been shown that math anxiety and math ability share common genetic etiology (Wang et al., 2014).

Nevertheless, the question of whether deficient numerical skills lead to math anxiety or rather math anxiety leads to deficient mathematical performance, is still under debate. Recent findings cast doubt on the idea that deficits in basic numerical processing underlie math anxiety (e.g., Maloney et al., 2010, 2011). Devine et al. (2018) found a dissociation between cognitive and emotional math problems in a large sample of children, despite having a significant percentage of co-occurrence. In addition, the assumption that math anxiety influences numerical cognition skills is supported by the finding showing that children diagnosed with math learning disabilities in grades 4–7 demonstrated an increase in math performance after training that helped them reduce their math anxiety level (Kamann and Wong, 1993). It is suggested that worries and intrusive thoughts characteristic of anxiety, may disrupt thinking processes when faced with a math task (Chang and Beilock, 2016) and thus, consume valuable attentional resources (Ashcraft and Kirk, 2001; Maloney and Beilock, 2012; Park et al., 2014). However, note that longitudinal studies suggest that math anxiety may be the result of a deficit in numerical cognition skills in students who began school as low mathematics achievers (Ma and Xu, 2004a).

Recent research implies that the relationship between math anxiety and math performance is bidirectional (Carey et al., 2016; Foley et al., 2017; Ramirez et al., 2018). For instance, a longitudinal study involving very young students (first to second grade) indicates the although math performance level at school entry (Duncan et al., 2007) is a strong predictor of math anxiety, a reciprocal relationship between math anxiety and math performance was observed even after a short exposure to formal education (Gunderson et al., 2018). Others have shown that there may be unidirectional relations between math anxiety and poor math performance

(e.g., Ashcraft and Moore, 2009). Math anxiety can have a direct effect on math performance (Ashcraft and Kirk, 2001; Beilock and Maloney, 2015), but also an indirect effect through avoidance behavior (Hembree, 1990; Ashcraft and Ridley, 2005).

It may be concluded, then, that in some cases deficient numerical skills can result in math anxiety, but depending on the interaction with other risk factors (e.g., **Figure 1**), math anxiety may harm mathematical performance.

In addition to numerical cognitive factors, affective factors, such as motivation or self-esteem, may serve as protectors. For example, math motivation can help overcome anxiety-related responses (Chang and Beilock, 2016). In support of this notion, a negative linear correlation has been observed between math anxiety and math performance in adolescents and adults with low math motivation, whereas an inverted-U curvilinear relationship has been found in more motivated students (Wang et al., 2015). Accordingly, contemporary functional MRI research has indicated that high activations in motivation-related brain regions, reduces the negative effects of high math anxiety on performance (Lyons and Beilock, 2011).

Similarly, thoughts and feelings about the self have been found to have an important role in educational outcomes (Lee, 2009). For example, Hembree (1990) found a negative correlation between math anxiety and enjoyment of math, self confidence in math, opinion about the usefulness of math and attitudes toward math teachers. In Hoffman's (2010) study, the compensatory relationship between self-efficacy and math anxiety was related to problem-solving efficiency. This finding supports the role of self-efficacy, which is defined as one's self-belief about the ability to produce successful outcomes (Bandura, 1997), in reducing math anxiety (Lee, 2009). Likewise, self-concept, which refers to how the individual perceives his or her own ability in a specific discipline (Bandura, 1986; Marsh, 2006), has also been found to mediate the link between math anxiety and performance among third and fifth graders (Justicia-Galiano et al., 2017). However, other researchers have argued that low self-concept and self-esteem is the result of math anxiety (Ahmed et al., 2012). Recently, Mammarella et al. (2018) demonstrated that the lower the self-concept, the higher the risk of developing anxiety. Similarly, path analysis and cluster analysis showed that academic resilience is predicted by self-efficacy (confidence), coordination (planning), control, commitment (persistence) and highly relevant to the current model, low anxiety (Martin and Marsh, 2006). In conclusion, current research is inconclusive and suggests that affective factors may act either as mediating or moderating math anxiety or even as part of the heterogeneous symptoms.

## Summary: Predispositions and Clinical Interventions

Within-child factors may serve as predispositions for math anxiety, but the opposite is also true. As indicated in **Figure 1** and in the above summary, people who acquire none of these predispositions should be less prone to develop math anxiety. Regardless of the specific within-child factor, math

anxiety narrows the working memory span when dealing with math tasks (Ashcraft and Kirk, 2001; Passolunghi et al., 2016; Shi and Liu, 2016; Ching, 2017; for working memory and anxiety see Moran, 2016). Therefore, suggested interventions for math anxiety typically include (general) anxiety-reducing methods. Examples of such interventions include Acceptance and Commitment Therapy (ACT) or systematic desensitization (Zettle, 2003), focused breathing exercise prior to the arithmetic test (Brunyé et al., 2013), emotion regulation strategies (Pizzie and Kraemer, 2018) and extensive one-on-one math tutoring (Supekar et al., 2015). It has been shown that reducing typical anxiety symptoms frees more working memory resources for math performance. Yet, the improvement in math performance after math tutoring (Supekar et al., 2015) can also account for the reduction in math anxiety levels by reducing failure experiences.

## ENVIRONMENTAL FACTORS: MEDIATING AND MODERATING PROCESSES

Within-child factors provide only a partial explanation of math anxiety development. In the above cited twin study, for example, a major proportion of the variance in math anxiety was accounted for by non-shared environmental factors (Wang et al., 2014).

Children spend most of their life at home or school, and are strongly influenced by interactions with parents, family members, teachers and peers. Our model suggests that a history of mathematically-related aversive outcomes resulting from social interactions, as well as poor modeling (e.g., teachers with math anxiety) or inappropriate math instruction strategies, may all lead to negative beliefs about mathematical competence and contribute to the development of math anxiety (Beilock et al., 2010). Indeed, numerous studies show that inappropriate instruction strategy may lead to the development of math anxiety (e.g., Baroody and Hume, 1991; Jackson and Leffingwell, 1999). According to Curtain-Phillips (1999), teachers need to re-examine traditional teaching methods and use methods which include less lectures, more student directed classes and more discussion. Thus, adverse mathematically-related pedagogical and social events during development, particularly those involving teachers (Beilock et al., 2010; Gunderson et al., 2012) and parents (Gunderson et al., 2012; Maloney et al., 2015; Daches Cohen and Rubinsten, 2017), are dynamically combined with maladaptive predispositions and may lead to math anxiety. We elaborate below.

### Parenting Style

Though many parents see math education as the school's responsibility (Cannon and Ginsburg, 2008), children themselves seek math help from their parents and teachers expect parents to help their children with their homework (Maloney et al., 2015). However, parenting practices, such as pressure to maintain high achievements (Daches Cohen and Rubinsten, 2017) and involvement in math-learning processes (Roberts and Vukovic, 2011), have been found to increase children's math anxiety. In particular, math-anxious parents may trigger, or intensify,

their child's math anxiety, especially when these parents report being extensively involved in helping their child with math homework (Maloney et al., 2015; Daches Cohen and Rubinsten, 2017).

The effect of parental math anxiety on children's math anxiety level was mostly demonstrated by studying mother-child dyads (Casad et al., 2015; Maloney et al., 2015; Daches Cohen and Rubinsten, 2017), but in at least two studies (Casad et al., 2015; Maloney et al., 2015) the sample was not initially limited to mothers. Additionally, one study found that mother-daughter dyads showed the most significant parental math anxiety effect (Daches Cohen and Rubinsten, 2017). A longitudinal study confirmed the effect: that is, the perceptions of mothers regarding their 7th grade children were associated with the career choices of their daughters, but not of their sons (Casad et al., 2015). Such gender bias patterns can explain why more males take advanced math courses and choose math related careers (Bleeker and Jacobs, 2004; Gunderson et al., 2012).

Parents, especially mothers (who were simply those that were studied the most), have an important role in the belief systems of their children, especially daughters, regarding math ability, self-efficacy and math anxiety. Thus, it may be important to encourage parents to act in order to reduce their own math anxiety as well as that of their children, and to encourage their children to pursue challenging courses and careers (Scarpello, 2007).

### Social Style: Teachers

Math anxious teachers may generate math anxiety in their students and affect its intensity (Martinez, 1987). However, this pattern seems to exhibit gender asymmetry. The level of math anxiety among elementary school female teachers was found to affect the math achievements of their female but not of their male students (Beilock et al., 2010). Similarly, female students of high math-anxious female teachers acquired negative stereotypes about girls and math, known to be related to math anxiety (Hembree, 1990). The mechanism of this gender asymmetry might be explained by the identification process of girls with their female teachers as a same-gender role model (Bussey and Bandura, 1984), which probably pushes girls to identify with their female teacher's negative attitude toward math (Gunderson et al., 2012).

### Teachers and Learnt Numerical Information

Math anxiety was also found to have a strong link with the learnt symbolic numerical information (such as arithmetic or Arabic numerals; e.g., Maloney et al., 2011; Dietrich et al., 2015). This link reflects the complex pathways towards the development of math anxiety, since it has several possible explanations, such as a genetic risk factor associated with poor math ability, an underlying neurological deficit in symbolic numerical processing, or exposure to inappropriate math instruction strategies. Negative pedagogical experiences with these learnt symbols (Cargnelutti et al., 2017; Gunderson et al., 2018) may lead to threat related attentional bias specifically towards learnt numerical information (that has been linked to negative valence during development, see Rubinsten et al., 2015). Supporting the argument that math anxiety is activated specifically during

involvement with learnt numerical information, math-anxious individuals were found to exhibit a deficit in the counting (an exact symbolic linguistic skill strongly associated with formal schooling; Gallistel and Gelman, 1992; Cordes et al., 2001) but not in the subitizing range (an exact symbolic linguistic skill that usually develops in the preschool years), with working memory as a mediator of this effect (Maloney et al., 2010). Moreover, math-anxious individuals showed reduced accuracy in mental representations of learnt symbolic but not innate non-symbolic numerical magnitudes or innate spatial abilities (Maloney et al., 2011; Dietrich et al., 2015; Douglas and LeFevre, 2018).

### Teachers, Parents and Negative Beliefs

We propose that an accumulation of adverse pedagogical and social events during development, involving teachers (Beilock et al., 2010; Gunderson et al., 2012) and parents (Gunderson et al., 2012; Daches Cohen and Rubinsten, 2017; Maloney et al., 2015), in *dynamic* combination with maladaptive mechanisms (predispositions), may lead to math anxiety through the creation of negative beliefs acting either as a result of math anxiety (symptoms; see bottom of **Figure 1**) or as mediators, moderators, or causes of math anxiety. Research into the mediating pathways between adverse environmental experiences and negative beliefs is in its infancy, but a recent study found that the more teachers emphasized the need to demonstrate competence in the classroom, the more their students believed that ability is stable and inflexible (Park et al., 2016). Similarly, it has been shown that parents and teachers significantly shape the child's math attitudes (Gunderson et al., 2012; Park et al., 2016). Future longitudinal studies can help reveal the actual causal direction.

### Wider Social Effects

Cultural norms have a significant effect on math anxiety expression (Stoet et al., 2016; Foley et al., 2017). For example, countries with higher math achievement have fewer students with math anxiety and vice versa (Organization for Economic Co-operation and Development, 2013). Additionally, Asian countries (Korea, Japan and Thailand) showed a high prevalence of math anxiety, while Western European countries (Austria, Germany, Liechtenstein, Sweden and Switzerland) showed a low prevalence of math anxiety (Lee, 2009). Moreover, students in some high math achieving countries (mostly East Asian, such as Singapore or Korea) showed a high prevalence of math anxiety, while a low prevalence of math anxiety was evident among students in other high achieving countries (such as Switzerland; Foley et al., 2017). This disparity can be attributed to cultural differences, due to the pursuit of high academic achievements across high math achieving countries, inducing high math anxiety among students in these countries (Stankov, 2010). Though the symptoms of math anxiety are relatively constant across cultures, their expression varies depending on the mathematical concerns of a given culture. For example, gender differences in math anxiety may partly result from cultural pressure to reduce math anxiety in males while tolerating it in females. Indeed, economically-developed and gender-equal



countries showed lower overall math anxiety occurrence, but a surprisingly larger national gender difference in the distribution of math anxiety (Stoet et al., 2016) which may be attributed, in part, to the well-established gender differences in occupational interests (Leder, 1990; Kenway and Willis, 1993; Su et al., 2009). Finally, culture may influence the point at which math anxiety is seen as an obstacle in one's life, thus affecting diagnosis rates. Given that most individuals spend their entire life in a given culture, its characteristics may be important for manifestations of math anxiety across the lifespan.

## Summary: Environmental Factors and Clinical Interventions

Countermeasures for these environmental factors must stem from the education curriculum and cultural/social climate change (Martinez, 1987; Scarpello, 2007; Organization for Economic Co-operation and Development, 2013). For example, math anxiety was reduced when using teaching methods that concretize mathematics concepts (Vinson, 2001). Martinez (1987) listed several guidelines for an anxiety-free class and suggested that interventions that focus on the teacher's own math fears might "break the chain" and prevent the continuous spreading of math anxiety. With a wider cultural perspective, the education system should be more sensitive to the different needs of males and females, as their attitudes toward math may differ (Geist, 2010).

## CONCLUSION

The current model focuses on the trajectories of math anxiety from a developmental, dynamic and bio-psycho-social perspective, which hold that math anxiety results from multiple causal interacting influences. Namely, heterogeneous symptoms of math anxiety emerge from multiple developmental pathways that reflect the dynamic interplay between characteristics of children (intrinsic predispositions including heritage, neural functions and cognitive-processing) and their environment (teachers, parents and wider social effects) over time. Although some of the relationships are still hypothetical, the evidence to support such a model is accumulating and indicates that predispositions and environmental factors may indeed enhance or counteract each other.

Thus, for example, for intrinsically biologically vulnerable individuals, adverse math learning experiences may result in threat-related attentional bias towards learnt numerical information as well as in maladaptive beliefs about individual

mathematical (dis)abilities, with difficulties in controlling the outcomes of mathematical situations, which may lead to ruminations. In turn, these negative beliefs and ruminations may be linked to behavioral, somatic and emotional responses of math anxiety (see heterogeneous symptoms—bottom of **Figure 1**). Avoidance of future numerical activities may also act as a behavioral manifestation of math anxiety (Ashcraft, 2002), which in turn reduces positive opportunities to acquire numerical skills and limits the development of good math proficiency (Krinzinger et al., 2009). Thus, a vicious cycle might be established, increasing the math anxiety level.

Future research should study the developmental course of math anxiety, in an attempt to identify different groups of individuals with distinct trajectories, critical to understanding the heterogeneity of math anxiety symptoms. In addition, future studies are urged to explore the additive or interacting effects of multiple factors in the development of math anxiety.

From a practical point of view, intervention programs should take into account the complex pathways towards the development of math anxiety, which lead to heterogeneity in the continuity and manifestations of math anxiety, beyond focusing on (general) anxiety-reducing methods. Awareness of the heterogeneity in both causes and symptoms of math anxiety will enable educators and psychologists to identify as early and accurately as possible students who have developed or are at risk to develop math anxiety. Early and accurate diagnosis of math anxiety will, in turn, allow implementation of a Response to Intervention (RTI) model which has three basic components (Fuchs and Fuchs, 2005; Brown-Chidsey and Steege, 2011). First, choosing a research-based intervention that matches the student's educational and behavioral needs. Second, using progress monitoring in order to consider the need for changes in instruction or in the goals of intervention. The third component includes making educational decisions about the extent of support provided to students according to their therapeutic history and the information obtained in the progress of monitoring the severity of their difficulties.

## AUTHOR CONTRIBUTIONS

OR conceived of the presented idea and developed the theory. All authors discussed the theory and contributed to the final manuscript. All authors participated in the writing and the revision of the manuscript.

## REFERENCES

- Affrunti, N. W., and Ginsburg, G. S. (2012). Exploring parental predictors of child anxiety: the mediating role of child interpretation bias. *Child Youth Care Forum* 41, 517–527. doi: 10.1007/s10566-012-9186-6
- Ahmed, W., Minnaert, A., Kuyper, H., and van der Werf, G. (2012). Reciprocal relationships between math self-concept and math anxiety. *Learn. Individ. Differ.* 22, 385–389. doi: 10.1016/j.lindif.2011.12.004
- Artemenko, C., Daroczy, G., and Nuerk, H. C. (2015). Neural correlates of math anxiety—an overview and implications. *Front. Psychol.* 6:1333. doi: 10.3389/fpsyg.2015.01333
- Ashcraft, M. H. (2002). Math anxiety: personal, educational, and cognitive consequences. *Curr. Dir. Psychol. Sci.* 11, 181–185. doi: 10.1111/1467-8721.00196
- Ashcraft, M. H., and Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *J. Exp. Psychol. Gen.* 130, 224–237. doi: 10.1037/0096-3445.130.2.224
- Ashcraft, M. H., Krause, J. A., and Hopko, D. R. (2007). "Is math anxiety a mathematical learning disability?" in *Why Is Math So Hard for Some Children? The Nature and Origins of Mathematical Learning Difficulties and Disabilities*, eds D. B. Berch and M. M. M. Mazzocco (Baltimore, MD: Paul H Brookes Publishing), 329–348.



- Ashcraft, M. H., and Moore, A. M. (2009). Mathematics anxiety and the affective drop in performance. *J. Psychoeduc. Assess.* 27, 197–205. doi: 10.1177/0734282908330580
- Ashcraft, M. H., and Ridley, K. S. (2005). “Math anxiety and its cognitive consequences: a tutorial review.” in *The Handbook of Mathematical Cognition*, ed. J. D. Campbell (New York: Psychology Press), 315–327.
- Bandura, A. (1986). *Social Foundations of Thought and Action: A Social Cognitive Theory*. Englewood Cliffs, NJ: Prentice-Hall, Inc.
- Bandura, A. (1997). *Self-Efficacy: The Exercise of Control*. New York, NY: W.H. Freeman and Company.
- Bar-Haim, Y., Holoshitz, Y., Eldar, S., Frenkel, T. I., Muller, D., Charney, D. S., et al. (2010). Life-threatening danger and suppression of attention bias to threat. *Am. J. Psychiatry* 167, 694–698. doi: 10.1176/appi.ajp.2009.09070956
- Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., and Van Ijzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: a meta-analytic study. *Psychol. Bull.* 133, 1–24. doi: 10.1037/0033-2909.133.1.1
- Baroody, A. J., and Hume, J. (1991). Meaningful mathematics instruction: the case of fractions. *Rem. Spec. Educ.* 12, 54–68. doi: 10.1177/074193259101200307
- Baten, E., and Desoete, A. (2018). Mathematical (Dis)abilities within the opportunity-propensity model: the choice of math test matters. *Front. Psychol.* 9:667. doi: 10.3389/fpsyg.2018.00667
- Beilock, S. (2010). *Choke: What the Secrets of the Brain Reveal About Getting it Right When You Have to*. New York, NY: Simon and Schuster.
- Beilock, S. L., and Maloney, E. A. (2015). Math anxiety: a factor in math achievement not to be ignored. *Policy Insights Behav. Brain Sci.* 2, 4–12. doi: 10.1177/2372732215601438
- Beilock, S. L., Gunderson, E. A., Ramirez, G., and Levine, S. C. (2010). Female teachers’ math anxiety affects girls’ math achievement. *Proc. Natl. Acad. Sci. U S A* 107, 1860–1863. doi: 10.1073/pnas.0910967107
- Berkowitz, T., Schaeffer, M. W., Maloney, E. A., Peterson, L., Gregor, C., Levine, S. C., et al. (2015). Math at home adds up to achievement in school. *Science* 350, 196–198. doi: 10.1126/science.aac7427
- Bishop, S. J. (2009). Trait anxiety and impoverished prefrontal control of attention. *Nat. Neurosci.* 12, 92–98. doi: 10.1038/nn.2242
- Bleeker, M. M., and Jacobs, J. E. (2004). Achievement in math and science: do mothers’ beliefs matter 12 years later? *J. Educ. Psychol.* 96, 97–109. doi: 10.1037/0022-0663.96.1.97
- Brown-Chidsey, R., and Steege, M. W. (2011). *Response to Intervention: Principles and Strategies for Effective Practice*. New York, NY: Guilford Press.
- Brunyé, T. T., Mahoney, C. R., Giles, G. E., Rapp, D. N., Taylor, H. A., and Kanarek, R. B. (2013). Learning to relax: evaluating four brief interventions for overcoming the negative emotions accompanying math anxiety. *Learn. Individ. Differ.* 27, 1–7. doi: 10.1016/j.lindif.2013.06.008
- Bussey, K., and Bandura, A. (1984). Influence of gender constancy and social power on sex-linked modeling. *J. Pers. Soc. Psychol.* 47, 1292–1302. doi: 10.1037//0022-3514.47.6.1292
- Byrnes, J. P., and Miller, D. C. (2007). The relative importance of predictors of math and science achievement: an opportunity-propensity analysis. *Contemp. Educ. Psychol.* 32, 599–629. doi: 10.1016/j.cedpsych.2006.09.002
- Byrnes, J. P., and Wasik, B. A. (2009). Factors predictive of mathematics achievement in kindergarten, first and third grades: an opportunity-propensity analysis. *Contemp. Educ. Psychol.* 34, 167–183. doi: 10.1016/j.cedpsych.2009.01.002
- Cannon, J., and Ginsburg, H. P. (2008). “Doing the math”: maternal beliefs about early mathematics versus language learning. *Early Educ. Dev.* 19, 238–260. doi: 10.1080/10409280801963913
- Carey, E., Hill, F., Devine, A., and Szűcs, D. (2016). The chicken or the egg? The direction of the relationship between mathematics anxiety and mathematics performance. *Front. Psychol.* 6:1987. doi: 10.3389/fpsyg.2015.01987
- Cargnelutti, E., Tomasetto, C., and Passolunghi, M. C. (2017). How is anxiety related to math performance in young students? A longitudinal study of Grade 2 to Grade 3 children. *Cogn. Emot.* 31, 755–764. doi: 10.1080/02699931.2016.1147421
- Casad, B. J., Hale, P., and Wachs, F. L. (2015). Parent-child math anxiety and math-gender stereotypes predict adolescents’ math education outcomes. *Front. Psychol.* 6:1597. doi: 10.3389/fpsyg.2015.01597
- Chang, H., and Beilock, S. L. (2016). The math anxiety-math performance link and its relation to individual and environmental factors: a review of current behavioral and psychophysiological research. *Curr. Opin. Behav. Sci.* 10, 33–38. doi: 10.1016/j.cobeha.2016.04.011
- Ching, B. H.-H. (2017). Mathematics anxiety and working memory: longitudinal associations with mathematical performance in Chinese children. *Contemp. Educ. Psychol.* 51, 99–113. doi: 10.1016/j.cedpsych.2017.06.006
- Chorpita, B. F., Albano, A. M., and Barlow, D. H. (1996). Cognitive processing in children: relation to anxiety and family influences. *J. Clin. Child Psychol.* 25, 170–176. doi: 10.1207/s15374424jccp2502\_5
- Cisler, J. M., and Koster, E. H. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: an integrative review. *Clin. Psychol. Rev.* 30, 203–216. doi: 10.1016/j.cpr.2009.11.003
- Cordes, S., Gelman, R., Gallistel, C. R., and Whalen, J. (2001). Variability signatures distinguish verbal from nonverbal counting for both large and small numbers. *Psychon. Bull. Rev.* 8, 698–707. doi: 10.3758/bf03196206
- Curtain-Phillips, M. (1999). *Math Attack: How to Reduce Math Anxiety in the Classroom, at Work, and Everyday Personal Use*. New York, NY: Morris publishing.
- Daches Cohen, L., and Rubinsten, O. (2017). Mothers, intrinsic math motivation, arithmetic skills, and math anxiety in elementary school. *Front. Psychol.* 8:1939. doi: 10.3389/fpsyg.2017.01939
- Devine, A., Hill, F., Carey, E., and Szűcs, D. (2018). Cognitive and emotional math problems largely dissociate: prevalence of developmental dyscalculia and mathematics anxiety. *J. Educ. Psychol.* 110, 431–444. doi: 10.1037/edu0000222
- Dietrich, J. F., Huber, S., Moeller, K., and Klein, E. (2015). The influence of math anxiety on symbolic and non-symbolic magnitude processing. *Front. Psychol.* 6:1621. doi: 10.3389/fpsyg.2015.01621
- Dineen, K. A., and Hadwin, J. A. (2004). Anxious and depressive symptoms and children’s judgements of their own and others’ interpretation of ambiguous social scenarios. *J. Anxiety Disord.* 18, 499–513. doi: 10.1016/S0887-6185(03)00030-6
- Douglas, H. P., and LeFevre, J.-A. (2018). Exploring the influence of basic cognitive skills on the relation between math performance and math anxiety. *J. Numer. Cogn.* 3, 642–666. doi: 10.5964/jnc.v3i3.113
- Dowker, A., Bennett, K., and Smith, L. (2012). Attitudes to mathematics in primary school children. *Child Dev. Res.* 2012, 1–8. doi: 10.1155/2012/124939
- Dowker, A., Sarkar, A., and Looi, C. Y. (2016). Mathematics anxiety: what have we learned in 60 years? *Front. Psychol.* 7:508. doi: 10.3389/fpsyg.2016.00508
- Dreger, R. M., and Aiken, L. R. (1957). The identification of number anxiety in a college population. *J. Educ. Psychol.* 48, 344–351. doi: 10.1037/h0045894
- Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P. K., et al. (2007). School readiness and later achievement. *Dev. Psychol.* 43, 1428–1446. doi: 10.1037/0012-1649.43.6.1428
- Estrada, C. A., Martin-Hryniewicz, M., Peek, B. T., Collins, C., and Byrd, J. C. (2004). Literacy and numeracy skills and anticoagulation control. *Am. J. Med. Sci.* 328, 88–93. doi: 10.1097/00000441-200408000-00004
- Eysenck, M., Derakshan, N., Santos, R., and Calvo, M. (2007). Anxiety and cognitive performance: attentional control theory. *Emotion* 7, 336–353. doi: 10.1037/1528-3542.7.2.336
- Foley, A. E., Herts, J. B., Borgonovi, F., Guerriero, S., Levine, S. C., and Beilock, S. L. (2017). The math anxiety-performance link: a global phenomenon. *Curr. Dir. Psychol. Sci.* 26, 52–58. doi: 10.1177/0963721416672463
- Fuchs, D., and Fuchs, L. S. (2005). Responsiveness-to-intervention: a blueprint for practitioners, policymakers, and parents. *Teach. Except. Child.* 38, 57–61. doi: 10.1177/004005990503800112
- Gallistel, C. R., and Gelman, R. (1992). Preverbal and verbal counting and computation. *Cognition* 44, 43–74. doi: 10.1016/0010-0277(92)90050-r
- Geist, E. (2010). The anti-anxiety curriculum: combating math anxiety in the classroom. *J. Inst. Psychol.* 37, 24–31.
- Gerardi, K., Goette, L., and Meier, S. (2013). Numerical ability predicts mortgage default. *Proc. Natl. Acad. Sci. U S A* 110, 11267–11271. doi: 10.1073/pnas.1220568110
- Gierl, M. J., and Bisanz, J. (1995). Anxieties and attitudes related to mathematics in grades 3 and 6. *J. Exp. Educ.* 63, 139–158. doi: 10.1080/00220973.1995.9943818
- Gunderson, E. A., Park, D., Maloney, E. A., Beilock, S. L., and Levine, S. C. (2018). Reciprocal relations among motivational frameworks, math anxiety,

- and math achievement in early elementary school. *J. Cogn. Dev.* 19, 21–46. doi: 10.1080/15248372.2017.1421538
- Gunderson, E. A., Ramirez, G., Levine, S. C., and Beilock, S. L. (2012). The role of parents and teachers in the development of gender-related math attitudes. *Sex Roles* 66, 153–166. doi: 10.1007/s11199-011-0100-8
- Gunderson, E. A., Sorhagen, N. S., Gripshover, S. J., Dweck, C. S., Goldin-Meadow, S., and Levine, S. C. (2018). Parent praise to toddlers predicts fourth grade academic achievement via children's incremental mindsets. *Dev. Psychol.* 54, 397–409. doi: 10.1037/dev0000444
- Hartwright, C. E., Looi, C. Y., Sella, F., Inuggi, A., Santos, F. H., González-Salinas, C., et al. (2018). The neurocognitive architecture of individual differences in math anxiety in typical children. *Sci. Rep.* 8:8500. doi: 10.1038/s41598-018-26912-5
- Heckhausen, J., Wrosch, C., and Schulz, R. (2010). A motivational theory of life-span development. *Psychol. Rev.* 117, 32–60. doi: 10.1037/a0017668
- Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. *J. Res. Math. Educ.* 21, 33–46. doi: 10.2307/749455
- Hoffman, B. (2010). “I think I can, but I'm afraid to try”: the role of self-efficacy beliefs and mathematics anxiety in mathematics problem-solving efficiency. *Learn. Individ. Differ.* 20, 276–283. doi: 10.1016/j.lindif.2010.02.001
- Insnard, J., Magnin, M., Jung, J., Mauguère, F., and Garcia-Larrea, L. (2011). Does the insula tell our brain that we are in pain? *Pain* 152, 946–951. doi: 10.1016/j.pain.2010.12.025
- Jackson, C. D., and Leffingwell, R. J. (1999). The role of instructors in creating math anxiety in students from kindergarten through college. *Math. Teach.* 92, 583–586.
- Justicia-Galiano, M. J., Martín-Puga, M. E., Linares, R., and Pelegrina, S. (2017). Math anxiety and math performance in children: the mediating roles of working memory and math self-concept. *Br. J. Educ. Psychol.* 87, 573–589. doi: 10.1111/bjep.12165
- Kamann, M. P., and Wong, B. Y. (1993). Inducing adaptive coping self-statements in children with learning disabilities through self-instruction training. *J. Learn. Disabil.* 26, 630–638. doi: 10.1177/002221949302600913
- Kenway, J., and Willis, S. (1993). *Telling Tales: Girls and Schools Changing Their Ways*. Canberra: Department of Employment, Education and Training.
- Krinzinger, H., Kaufmann, L., and Willmes, K. (2009). Math anxiety and math ability in early primary school years. *J. Psychoeduc. Assess.* 27, 206–225. doi: 10.1177/0734282908330583
- Leder, G. C. (1990). “Gender differences in mathematics: an overview,” in *Mathematics and Gender*, eds E. Fennema and G. C. Leder (New York, NY: Teachers' College Press), 10–26.
- Lee, J. (2009). Universals and specifics of math self-concept, math self-efficacy, and math anxiety across 41 PISA 2003 participating countries. *Learn. Individ. Differ.* 19, 355–365. doi: 10.1016/j.lindif.2008.10.009
- Lerner, R. M. (2001). *Concepts and Theories of Human Development*. Mahwah, NJ: Lawrence Erlbaum.
- Lerner, R. M., and Busch-Rossnagel, N. A. (Eds). (2013). *Individuals as Producers of Their Development: A Life-Span Perspective*. London: Elsevier.
- Luijten, M., Veltman, D. J., Hester, R., Smits, M., Peplinkhuizen, L., and Franken, I. H. (2012). Brain activation associated with attentional bias in smokers is modulated by a dopamine antagonist. *Neuropsychopharmacology* 37, 2772–2779. doi: 10.1038/npp.2012.143
- Luo, Y. L., Kovas, Y., Haworth, C. M., and Plomin, R. (2011). The etiology of mathematical self-evaluation and mathematics achievement: understanding the relationship using a cross-lagged twin study from ages 9 to 12. *Learn. Individ. Differ.* 21, 710–718. doi: 10.1016/j.lindif.2011.09.001
- Lyons, I. M., and Beilock, S. L. (2011). Mathematics anxiety: separating the math from the anxiety. *Cereb. Cortex* 22, 2102–2110. doi: 10.1093/cercor/bhr289
- Lyons, I. M., and Beilock, S. L. (2012). When math hurts: math anxiety predicts pain network activation in anticipation of doing math. *PLoS One* 7:e48076. doi: 10.1371/journal.pone.0048076
- Ma, X. (1999). A meta-analysis of the relationship between anxiety toward mathematics and achievement in mathematics. *J. Res. Math. Educ.* 30, 520–540. doi: 10.2307/749772
- Ma, X., and Xu, J. (2004a). The causal ordering of mathematics anxiety and mathematics achievement: a longitudinal panel analysis. *J. Adolesc.* 27, 165–179. doi: 10.1016/j.adolescence.2003.11.003
- Ma, X., and Xu, J. (2004b). Determining the causal ordering between attitude toward mathematics and achievement in mathematics. *Am. J. Educ.* 110, 256–281. doi: 10.1086/383074
- Madjar, N., Zalsman, G., Weizman, A., Lev-Ran, S., and Shoval, G. (2016). Predictors of developing mathematics anxiety among middle-school students: a 2-year prospective study. *Int. J. Psychol.* 53, 426–432. doi: 10.1002/ijop.12403
- Malanchini, M., Rimfeld, K., Shakeshaft, N. G., Rodic, M., Schofield, K., Selzam, S., et al. (2017). The genetic and environmental etiology of spatial, mathematics and general anxiety. *Sci. Rep.* 7:42218. doi: 10.1038/srep42218
- Maloney, E. A., Ansari, D., and Fugelsang, J. A. (2011). The effect of mathematics anxiety on the processing of numerical magnitude. *Q. J. Exp. Psychol.* 64, 10–16. doi: 10.1080/17470218.2010.533278
- Maloney, E. A., and Beilock, S. L. (2012). Math anxiety: who has it, why it develops, and how to guard against it. *Trends Cogn. Sci.* 16, 404–406. doi: 10.1016/j.tics.2012.06.008
- Maloney, E. A., Ramirez, G., Gunderson, E. A., Levine, S. C., and Beilock, S. L. (2015). Intergenerational effects of parents' math anxiety on children's math achievement and anxiety. *Psychol. Sci.* 26, 1480–1488. doi: 10.1177/0956797615592630
- Maloney, E., Risko, E. F., Ansari, D., and Fugelsang, J. F. (2010). Mathematics anxiety affects counting but not subitizing during visual enumeration. *Cognition* 114, 293–297. doi: 10.1016/j.cognition.2009.09.013
- Mammarella, I. C., Donolato, E., Caviola, S., and Giofrè, D. (2018). Anxiety profiles and protective factors: a latent profile analysis in children. *Pers. Individ. Differ.* 124, 201–208. doi: 10.1016/j.paid.2017.12.017
- Marsh, H. W. (2006). *Self-Concept Theory, Measurement and Research Into Practice: The Role of Self-Concept in Educational Psychology*. Vernon-Wall Lecture: British Psychological Society.
- Martin, A. J., and Marsh, H. W. (2006). Academic resilience and its psychological and educational correlates: a construct validity approach. *Psychol. Schools* 43, 267–281. doi: 10.1002/pits.20149
- Martinez, J. G. R. (1987). Preventing math anxiety: a prescription. *Acad. Ther.* 23, 117–125. doi: 10.1177/105345128702300201
- Moran, T. P. (2016). Anxiety and working memory capacity: a meta-analysis and narrative review. *Psychol. Bull.* 142, 831–864. doi: 10.1037/bul0000051
- Muris, P., Rapee, R., Meesters, C., Schouten, E., and Geers, M. (2003). Threat perception abnormalities in children: the role of anxiety disorders symptoms, chronic anxiety, and state anxiety. *J. Anxiety Disord.* 17, 271–287. doi: 10.1016/s0887-6185(02)00199-8
- Nolen-Hoeksema, S., Wisco, B. E., and Lyubomirsky, S. (2008). Rethinking rumination. *Perspect. Psychol. Sci.* 3, 400–424. doi: 10.1111/j.1745-6924.2008.00088.x
- Núñez-Peña, M. I., and Suárez-Pellicioni, M. (2014). Less precise representation of numerical magnitude in high math-anxious individuals: an ERP study of the size and distance effects. *Biol. Psychol.* 103, 176–183. doi: 10.1016/j.biopsycho.2014.09.004
- O'Leary, K., Fitzpatrick, C. L., and Hallett, D. (2017). Math anxiety is related to some, but not all, experiences with math. *Front. Psychol.* 8:2067. doi: 10.3389/fpsyg.2017.02067
- Organization for Economic Co-operation and Development. (2013). *PISA 2012 Results: Ready to Learn: Students' Engagement, Drive and Self-Beliefs*. (Vol. III). Paris, France: Author.
- Park, D., Gunderson, E. A., Tsukayama, E., Levine, S. C., and Beilock, S. L. (2016). Young children's motivational frameworks and math achievement: relation to teacher-reported instructional practices, but not teacher theory of intelligence. *J. Educ. Psychol.* 108, 300–313. doi: 10.1037/edu0000064
- Park, D., Ramirez, G., and Beilock, S. L. (2014). The role of expressive writing in math anxiety. *J. Exp. Psychol. Appl.* 20, 103–111. doi: 10.1037/xap0000013
- Parsons, S., and Bynner, J. (2005). *Does Numeracy Matter More?*. London: Research and Development Centre for Adult Literacy and Numeracy.
- Passolunghi, M. C. (2011). Cognitive and emotional factors in children with mathematical learning disabilities. *Int. J. Disabil. Dev. Educ.* 58, 61–73. doi: 10.1080/1034912x.2011.547351
- Passolunghi, M. C., Caviola, S., De Agostini, R., Perin, C., and Mammarella, I. C. (2016). Mathematics anxiety, working memory, and mathematics performance

- in secondary-school children. *Front. Psychol.* 7:42. doi: 10.3389/fpsyg.2016.00042
- Paulus, M. P., and Stein, M. B. (2006). An insular view of anxiety. *Biol. Psychiatry* 60, 383–387. doi: 10.1016/j.biopsych.2006.03.042
- Phan, K. L., Wager, T., Taylor, S. F., and Liberzon, I. (2002). Functional neuroanatomy of emotion: a meta-analysis of emotion activation studies in PET and fMRI. *Neuroimage* 16, 331–348. doi: 10.1006/nimg.2002.1087
- Pizzie, R., and Kraemer, D. J. (2018). The influence of emotion regulation techniques on arousal and performance in math anxiety. *OSF [Preprint]*. doi: 10.17605/OSF.IO/F3D59
- Pletzer, B., Kronbichler, M., Nuerk, H. C., and Kerschbaum, H. H. (2015). Mathematics anxiety reduces default mode network deactivation in response to numerical tasks. *Front. Hum. Neurosci.* 9:202. doi: 10.3389/fnhum.2015.00202
- Pletzer, B., Wood, G., Moeller, K., Nuerk, H. C., and Kerschbaum, H. H. (2010). Predictors of performance in a real-life statistics examination depend on the individual cortisol profile. *Biol. Psychol.* 85, 410–416. doi: 10.1016/j.biopsycho.2010.08.015
- Ramirez, G., Chang, H., Maloney, E. A., Levine, S. C., and Beilock, S. L. (2016). On the relationship between math anxiety and math achievement in early elementary school: the role of problem solving strategies. *J. Exp. Child Psychol.* 141, 83–100. doi: 10.1016/j.jecp.2015.07.014
- Ramirez, G., Shaw, S. T., and Maloney, E. A. (2018). Math anxiety: past research, promising interventions, and a new interpretation framework. *Educ. Psychol.* 53, 145–164. doi: 10.1080/00461520.2018.1447384
- Reyna, V. F., Nelson, W. L., Han, P. K., and Dieckmann, N. F. (2009). How numeracy influences risk comprehension and medical decision making. *Psychol. Bull.* 135, 943–973. doi: 10.1037/a0017327
- Richardson, F. C., and Suinn, R. M. (1972). The mathematics anxiety rating scale. *J. Couns. Psychol.* 19, 551–554. doi: 10.1037/h0033456
- Ritchie, S. J., and Bates, T. C. (2013). Enduring links from childhood mathematics and reading achievement to adult socioeconomic status. *Psychol. Sci.* 24, 1301–1308. doi: 10.1177/0956797612466268
- Rivera-Batiz, F. L. (1992). Quantitative literacy and the likelihood of employment among young adults in the United States. *J. Hum. Resour.* 27, 313–328. doi: 10.2307/145737
- Roberts, S. O., and Vukovic, R. K. (2011). The relation between parental involvement and math anxiety: Implications for mathematics achievement. Society for Research on Educational Effectiveness. Washington, DC: Journal of Research for Educational Effectiveness.
- Robinson, O. J., Charney, D. R., Overstreet, C., Vytal, K., and Grillon, C. (2012). The adaptive threat bias in anxiety: amygdala-dorsomedial prefrontal cortex coupling and aversive amplification. *Neuroimage* 60, 523–529. doi: 10.1016/j.neuroimage.2011.11.096
- Rubinsten, O., Bialik, N., and Solar, Y. (2012). Exploring the relationship between math anxiety and gender through implicit measurement. *Front. Hum. Neurosci.* 6:279. doi: 10.3389/fnhum.2012.00279
- Rubinsten, O., Eidlin, H., Wohl, H., and Akibli, O. (2015). Attentional bias in math anxiety. *Front. Psychol.* 6:1539. doi: 10.3389/fpsyg.2015.01539
- Rubinsten, O., and Tannock, R. (2010). Mathematics anxiety in children with developmental dyscalculia. *Behav. Brain Funct.* 6:46. doi: 10.1186/1744-9081-6-46
- Sagvolden, T., Johansen, E. B., Aase, H., and Russell, V. A. (2005). A dynamic developmental theory of attention-deficit/hyperactivity disorder (ADHD) predominantly hyperactive/impulsive and combined subtypes. *Behav. Brain Sci.* 28, 397–418. doi: 10.1017/s0140525x05000075
- Sarkar, A., Dowker, A., and Kadosh, R. C. (2014). Cognitive enhancement or cognitive cost: trait-specific outcomes of brain stimulation in the case of mathematics anxiety. *J. Neurosci.* 34, 16605–16610. doi: 10.1523/JNEUROSCI.3129-14.2014
- Scarpello, G. (2007). Helping students get past math anxiety. *Tech. Connect. Educ. Careers* 82, 34–35.
- Schwartz, L. (2001). *A Mathematician Grappling With his Century*. Novosibirsk: Springer Science and Business Media.
- Shi, Z., and Liu, P. (2016). Worrying thoughts limit working memory capacity in math anxiety. *PLoS One* 11:e0165644. doi: 10.1371/journal.pone.0165644
- Stankov, L. (2010). Unforgiving confucian culture: a breeding ground for high academic achievement, test anxiety and selfdoubt? *Learn. Individ. Differ.* 20, 555–563. doi: 10.1016/j.lindif.2010.05.003
- Stoet, G., Bailey, D. H., Moore, A. M., and Geary, D. C. (2016). Countries with higher levels of gender equality show larger national sex differences in mathematics anxiety and relatively lower parental mathematics valuation for girls. *PLoS One* 11:e0153857. doi: 10.1371/journal.pone.0153857
- Su, R., Rounds, J., and Armstrong, P. I. (2009). Men and things, women and people: a meta-analysis of sex differences in interests. *Psychol. Bull.* 135, 859–884. doi: 10.1037/a0017364
- Suárez-Pellicioni, M., Núñez-Peña, M. I., and Colomé, À. (2013a). Mathematical anxiety effects on simple arithmetic processing efficiency: an event-related potential study. *Biol. Psychol.* 94, 517–526. doi: 10.1016/j.biopsycho.2013.09.012
- Suárez-Pellicioni, M., Núñez-Peña, M. I., and Colomé, À. (2013b). Abnormal error monitoring in math-anxious individuals: evidence from error-related brain potentials. *PLoS One* 8:e81143. doi: 10.1371/journal.pone.0081143
- Suárez-Pellicioni, M., Núñez-Peña, M. I., and Colomé, À. (2014). Reactive recruitment of attentional control in math anxiety: an ERP study of numeric conflict monitoring and adaptation. *PLoS One* 9:e99579. doi: 10.1371/journal.pone.0099579
- Suárez-Pellicioni, M., Núñez-Peña, M. I., and Colomé, À. (2015). Attentional bias in high math-anxious individuals: evidence from an emotional Stroop task. *Front. Psychol.* 6:1577. doi: 10.3389/fpsyg.2015.01577
- Suárez-Pellicioni, M., Núñez-Peña, M. I., and Colomé, À. (2016). Math anxiety: a review of its cognitive consequences, psychophysiological correlates, and brain bases. *Cogn. Affect. Behav. Neurosci.* 16, 3–22. doi: 10.3758/s13415-015-0370-7
- Supekar, K., Iuculano, T., Chen, L., and Menon, V. (2015). Remediation of childhood math anxiety and associated neural circuits through cognitive tutoring. *J. Neurosci.* 35, 12574–12583. doi: 10.1523/JNEUROSCI.0786-15.2015
- Van Bockstaele, B., Verschuere, B., Tibboel, H., De Houwer, J., Crombez, G., and Koster, E. H. (2014). A review of current evidence for the causal impact of attentional bias on fear and anxiety. *Psychol. Bull.* 140, 682–721. doi: 10.1037/a0034834
- Vinso, B. M. (2001). A comparison of preservice teachers' mathematics anxiety before and after a methods class emphasizing manipulatives. *Early Child. Educ. J.* 29, 89–94. doi: 10.1023/A:1012568711257
- Wang, Z., Hart, S. A., Kovas, Y., Lukowski, S., Soden, B., Thompson, L. A., et al. (2014). Who is afraid of math? Two sources of genetic variance for mathematical anxiety. *J. Child Psychol. Psychiatry* 55, 1056–1064. doi: 10.1111/jcpp.12224
- Wang, Z., Lukowski, S. L., Hart, S. A., Lyons, I. M., Thompson, L. A., Kovas, Y., et al. (2015). Is math anxiety always bad for math learning? The role of math motivation. *Psychol. Sci.* 26, 1863–1876. doi: 10.1177/0956797615602471
- Wigfield, A., and Meece, J. L. (1988). Math anxiety in elementary and secondary school students. *J. Educ. Psychol.* 80, 210–216. doi: 10.1037/0022-0663.80.2.210
- Woloshin, S., Schwartz, L. M., Moncur, M., Gabriel, S., and Tosteson, A. N. (2001). Assessing values for health: numeracy matters. *Med. Decis. Making* 21, 382–390. doi: 10.1177/0272989X0102100505
- Young, C. B., Wu, S. S., and Menon, V. (2012). The neurodevelopmental basis of math anxiety. *Psychol. Sci.* 23, 492–501. doi: 10.1177/0956797611429134
- Zettle, R. D. (2003). Acceptance and commitment therapy (ACT) vs. systematic desensitization in treatment of mathematics anxiety. *Psychol. Rec.* 53, 197–215. doi: 10.1007/bf03395440

**Conflict of Interest Statement:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Copyright © 2018 Rubinsten, Marciano, Eidlin Levy and Daches Cohen. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.