# Mathematics anxiety and cognition: An integrated neural network model

Moustafa, Ahmed A.; Porter, Angela; Megreya, Ahmed M.

*Published in:*
Reviews in the Neurosciences

*DOI:*
10.1515/revneuro-2019-0068

Ahmed A. Moustafa*, Angela Porter* and Ahmed M. Megreya

# Mathematics anxiety and cognition: an integrated neural network model

https://doi.org/10.1515/revneuro-2019-0068
Received July 15, 2019; accepted August 7, 2019; previously published online November 14, 2019

**Abstract:** Many students suffer from anxiety when performing numerical calculations. Mathematics anxiety is a condition that has a negative effect on educational outcomes and future employment prospects. While there are a multitude of behavioral studies on mathematics anxiety, its underlying cognitive and neural mechanism remain unclear. This article provides a systematic review of cognitive studies that investigated mathematics anxiety. As there are no prior neural network models of mathematics anxiety, this article discusses how previous neural network models of mathematical cognition could be adapted to simulate the neural and behavioral studies of mathematics anxiety. In other words, here we provide a novel integrative network theory on the links between mathematics anxiety, cognition, and brain substrates. This theoretical framework may explain the impact of mathematics anxiety on a range of cognitive and neuropsychological tests. Therefore, it could improve our understanding of the cognitive and neurological mechanisms underlying mathematics anxiety and also has important applications. Indeed, a better understanding of mathematics anxiety could inform more effective therapeutic techniques that in turn could lead to significant improvements in educational outcomes.

**Keywords:** amygdala; cognition; distraction; inhibition; mathematics anxiety; neural networks; prefrontal cortex.

***Corresponding authors: Ahmed A. Moustafa,** School of Social Sciences and Psychology, Western Sydney University, 2 Bullecourt Ave, Milperra, 2214 Sydney, New South Wales, Australia; and Marcs Institute for Brain and Behaviour, Western Sydney University, 2 Bullecourt Ave, Milperra, 2214 Sydney, New South Wales, Australia, e-mail: a.moustafa@westernsydney.edu.au; and **Angela Porter,** School of Social Sciences and Psychology, Western Sydney University, 2 Bullecourt Ave, Milperra, 2214 Sydney, New South Wales, Australia,
e-mail: 18919703@student.westernsydney.edu.au
**Ahmed M. Megreya:** College of Education, Qatar University, 1 Al Jamiaa St, 1021 Doha, Qatar

## Introduction

The term mathematics anxiety was coined by Dreger and Aiken (1957) and refers to a feeling of tension, apprehension, or even dread interfering with number manipulation and mathematical problem solving (Ashcraft and Faust, 1994; Ashcraft, 2002; Moustafa et al., 2017b; Lukowski et al., 2019a,b). Approximately 30% of 15-year-old students across Organisation for Economic Co-operation and Development (OECD) countries in 2012 reported feeling helpless or nervous when solving mathematics problems (OECD, 2013). Notably, mathematics anxiety can occur during and even before the exposure to mathematics activities (Artemenko et al., 2015). Therefore, it involves some detrimental influences such as impairing performance in numerical and mathematical tasks (Beilock, 2008; Lyons and Beilock, 2012; Braham and Libertus, 2018; Ramirez et al., 2013, 2018), avoiding mathematics subjects at school and university levels that impact students' prospective career choices (Hembree, 1990; Ashcraft and Krause, 2007), and affecting performance in everyday life activities (Holmes and Gathercole, 2014; Morsanyi et al., 2014). Mathematics anxiety shares similar features with other forms of anxiety, such as general anxiety (Baloglu, 1999; Kazelskis et al., 2000; Lauer et al., 2018).

Evidence indicates that mathematics anxiety is associated with a range of biological educational, psychological, and neural factors (Dowker et al., 2016). For example, mixed results were reported on the genetic basis of mathematics anxiety so that some studies reported that it relates to genetic (Lukowski et al., 2019a), environmental (Schaeffer et al., 2018), or an interaction of genetic and environmental factors (Dowker et al., 2016). Consistently, mathematics anxiety was found to be related to the complexity of mathematics activities (Faust et al., 1996), possibly as they require additional cognitive and working memory processes. In addition, a negative relationship between mathematics anxiety and educational level was reported (Ashcraft and Ridley, 2005). Furthermore, one study found that mathematics anxiety impairs mathematics performance in girls more than in boys (Van Mier et al., 2018). Other studies found exposure to gender stereotypes and negative attitudes by parents (Casad et al., 2015), and teachers (Beilock et al., 2010) affected levels of math anxiety in girls.

Many students report feeling anxious and thus avoid solving mathematics activities, which in turn impacts their career choices and further education (Hembree, 1990; Maloney et al., 2013). One study found that mathematics anxiety is related to interest in studying sciences (Chipman et al., 1992; Luttenberger et al., 2018). According to Hembree (1990), individuals with mathematics anxiety believe that mathematics is not useful and avoid mathematics courses and careers in science, technology, and engineering.

Mathematics anxiety is also associated with changes in several brain areas. For example, some studies reported an increase in amygdala activation, which is responsible for fear processing (Young et al., 2012; Kucian et al., 2018), and is involved in anxiety disorders (Tillfors et al., 2001; Sakai et al., 2005; van den Heuvel et al., 2005; McClure et al., 2007; Pillay et al., 2007; Blair et al., 2008; Evans et al., 2008; Guyer et al., 2008; Monk et al., 2008; Moustafa et al., 2013a). For example, Kucian et al. (2018) used MRI to investigate the relationship between mathematics anxiety and gray matter brain volume. They found that mathematics anxiety is related to changes in brain structure; in particular, math anxiety in children with and without developmental dyscalculia was related to a smaller volume of the right amygdala. Another study found that mathematics anxiety is associated with hyperactivity in the amygdala in children (Young et al., 2012). The same study also reported a positive association between mathematics anxiety and connectivity between the amygdala and the ventromedial prefrontal cortex. It is important to note that the ventromedial prefrontal cortex input to the amygdala was found to play a role in the reduction of fear and anxiety responses (Milad et al., 2005, 2009; Gold et al., 2016; Ganella et al., 2017), by inhibiting the intercalated cells of the amygdala (Moustafa et al., 2013a). It has been also suggested that the ventromedial prefrontal cortex-amygdala pathway plays a role in cognitive control and reduction of anxiety (Akirav and Maroun, 2007). However, it is not known if this pathway plays the same role in mathematics anxiety, which should be tested in future studies.

Mathematics anxiety is also associated with changes to the prefrontal cortex (Young et al., 2012; Artemenko et al., 2015), prefrontal dopamine levels (Julio-Costa et al., 2019), and the anterior cingulate cortex (Suarez-Pellicioni et al., 2013, 2016; Chang et al., 2017; Arsalidou et al., 2018). Klados et al. (2015) used ERP to investigate neural activity in individuals with mathematics anxiety during working memory and arithmetic tasks. They found that individuals with higher levels of self-reported mathematics anxiety showed lower cortical activation at frontocentral and centroparietal locations during the early stages of cognitive processing during simple arithmetic tasks. The results were independent of state and trait anxiety levels. Therefore, mathematics anxiety impacts a large network of cortical and subcortical brain areas. To the best of our knowledge, there are no prior theoretical or computational neural network models on mathematics anxiety. Our integrative neural network presented below will explain how all of several brain areas interact and impact mathematics anxiety. We also note that there have been prior reviews of mathematics anxiety in the literature (Sokolowski and Necka, 2016; Suarez-Pellicioni et al., 2016); however, these reviews did not provide an integrative framework to link neural and behavioral studies of mathematics anxiety.

## Methods

In this study, we provide a systematic review on neural and cognitive underpinnings of mathematics anxiety (see Figure 1). We have searched previous studies assessing mathematics anxiety in Pubmed, PsychoInfo, and also Google Scholar. Our search strategy included the following combination of key words from two sets. The first set included mathematics (or math) anxiety. The second set included cognition (or cognitive), neural networks, computational, model (or modeling), working memory, inhibition (or inhibitory), and attention (or attentional). Further, we have examined each paper carefully to ensure that the goal of the study is investigating mathematics anxiety. Studies that did not address mathematics anxiety were excluded. Figure 1 explains our search method and paper selection.

## Working memory and mathematics anxiety

Working memory refers to 'a brain system that provides temporary storage and manipulation of the information necessary for such complex cognitive tasks as language comprehension, learning, and reasoning' (Baddeley, 1992). Several studies reported a positive relationship between working memory and performance in mathematical activities (Meyer et al., 2010; also see Packiam Alloway et al., 2010; Raghubar et al., 2010; Passolunghi et al., 2016). Further, it was argued that the impact of mathematics anxiety on mathematical activities is mediated by working memory (Skagerlund et al., 2019). For

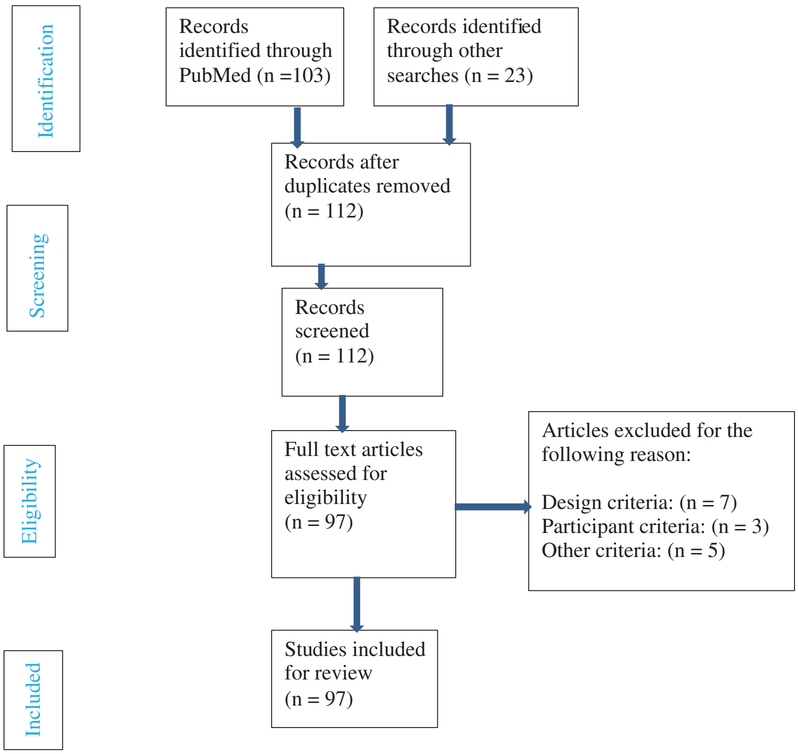


**Figure 1:** A systematic review on mathematics anxiety. Article search and selection process is shown.

example, some studies found that mathematical skills are related to working memory and executive functions using the Wisconsin Card Sorting Task (WCST) (Heaton et al., 1993; Bull and Scerif, 2001). Specifically, they found that impaired performance in the WCST is related to impaired performance in mathematics activities. Furthermore, cognitive training methods that target working memory processes were shown to enhance performance in mathematics activities (e.g. Takeuchi et al., 2010; Witt, 2011). Along these lines, Sanchez-Perez et al. (2017) designed a computer-based training program that was implemented into the classroom curriculum by teachers. They found that by combining training on working memory and mathematics tasks, typically developing children showed significant improvements in mathematics performance and on a go/no go task measuring the inhibition function of working memory.

It was suggested that individuals with high mathematics anxiety may have shorter working memory spans, possibly due to a disruption of central executive processes (Ashcraft and Kirk, 2001). One study reported that working memory enables mathematics learning (Skagerlund et al., 2019). Thus, mathematics anxiety may impair working memory performance, leading to inability to learn and perform mathematics problems (Soltanlou et al., 2019). Further, Soltanlou et al. (2019) suggested that if individuals have high working memory processes (perhaps due to genetic differences in COMT genes and/or prefrontal cortex function), mathematics anxiety may not consume all of their working memory resources and, thus, be able to learn and perform mathematics problems under anxiety conditions. Inconsistently, however, Ramirez et al. (2013) found that individuals with high working memory showed more mathematics anxiety symptoms and worse mathematics performance than those with low working memory. Ramirez et al. (2013) explained this finding using the assumption that individuals with high working memory might rely on strategies that involve working memory-intensive solutions to mathematics problems, and these strategies could be impaired by mathematics anxiety. Consistently, Mattarella-Micke et al. (2011) found that increased mathematics anxiety was associated with high working memory.

Converging with these results, it is well established that general anxiety impacts working memory performance (Lukasik et al., 2019). For example, anxiety induction was found to impair spatial and verbal working memory (Vytal et al., 2013). Accordingly, it is reasonable to conclude that working memory does impact mathematics anxiety, which can, in turn, impair performance in mathematics activities. Future experimental research needs to examine whether the induction of mathematics anxiety could impair working memory.

## Inhibitory and attentional performance: relation to mathematics anxiety

Several theories have been proposed to explain the effects of anxiety on cognitive performance, suggesting that anxiety leads to an impairment in the cognitive control system, which is the system responsible for the ability to adapt behavior depending on goals. According to the processing efficiency theory (Eysenck and Calvo, 1992), anxiety and worrying thoughts consume the limited resources of working memory, leaving less available for the current task. The attentional control theory (Eysenck et al., 2007), which is an extension of the processing efficiency theory, further describes the reduced efficiency of working memory (see working memory section for more discussion on this topic). Eysenck et al. (2007) proposed that anxious individuals have an imbalance between the top-down goal-directed attentional system and the bottom-up stimulus-driven attentional system; thus, they are influenced more by the stimulus-driven attentional system, resulting in an inability to inhibit distracting or irrelevant information (i.e. conflict) to the task at hand. Further, Eysenck et al. (2007) suggested that this inability occurs regardless of whether the distraction is external (such as irrelevant task information) or internal (from anxious thoughts). Accordingly, it is hypothesized that anxiety impairs processing efficiency to a greater extent than performance effectiveness, whereby anxious individuals exert increased effort to counter the negative effects of anxiety and attain a comparable quality of task performance (such as response accuracy) to less anxious individuals.

The conflict-monitoring hypothesis (Botvinick et al., 2001) proposes the existence of a system in the anterior cingulate cortex that monitors such conflicts and triggers an adjustment of attention to exert top-down control. However, the dual mechanisms of control framework (Braver et al., 2009; Hutchison, 2011; Braver, 2012; Lamichhane et al., 2018) further suggests that anxious individuals do not maintain top-down control continuously in a proactive manner, but instead, they exert control reactively only as needed when conflict or a task-relevant stimulus is detected, thereby causing susceptibility to distraction. To conclude, these theories suggest that anxiety impairs the cognitive control system affecting the individual's ability to adjust top-down control and goal-directed behavior.

Consistent with studies on general anxiety, early research on mathematics anxiety suggested that math-anxious individuals may have trouble inhibiting attention to distracting information (Hopko et al., 1998, 2002). More recently, Suarez-Pellicioni et al. (2014) investigated numerical conflict processing using a numerical Stroop paradigm, which is a standard test for examining the ability to inhibit irrelevant information during a numerical task (Stroop, 1935). In this task, a participant is presented with two single-digit numbers, each in different physical sizes, and must decide which number is numerically larger. A conflict can occur where the physical size is mismatched with the numerical size and needs to be inhibited. The size congruity effect or numerical interference effect occurs when it is easier to decide which number is numerically larger, when this number is also physically larger than when this number is physically smaller (Besner and Coltheart, 1979). For example, if presented with 'small-sized' 2 and 'big-sized' 8, it is easier to decide 8 is numerically larger than if presented with 'big-sized' 2 and 'small-sized' 8.

Suarez-Pellicioni et al. (2014) found that individuals with mathematics anxiety had larger interference effects (i.e. longer reaction times when experiencing conflict), which supports the existence of an impaired inhibition mechanism. Furthermore, using event-related potentials (ERPs), Suarez-Pellicioni et al. (2014) found that mathematics anxiety does not affect the early stages of cognitive control processing where the system monitors for conflict. Rather, it affects the later stages of processing with an abnormal upregulation of resources to solve the conflict that was encountered. Notably, results of Suarez-Pellicioni et al. (2014) support the dual mechanisms of control theory of reactive control, converging with theories of general anxiety. Therefore, Suarez-Pellicioni et al. (2014) concluded that attentional control and susceptibility to distraction are important factors related to mathematics anxiety. This conclusion requires further research.

Performance in attentional tasks is related to that of mathematics activities, in general (Wu et al., 2014). Further, some studies directly tested the relationship between mathematics anxiety and attentional processes. For example, mathematics anxiety was found to be associated with impaired attentional processes, and it is associated with larger $\beta$ oscillation, P300 amplitude, and stronger $\gamma$ waves during solving mathematics activities (Liu et al., 2019). Using an emotional Stroop task, which included both math-related and neutral words, Suarez-Pellicioni et al. (2015) found that high math-anxious individuals have larger reaction times than non-math-anxious participants on the math-related words. Along these lines, Rubinsten et al. (2015) used the dot prime task, in which participants attempt to identify whether a probe is one or two asterisks. Before the probe, a prime appeared on the screen, which included both math-related and neutral ones. Reaction time was lower in math-anxious individuals than in non-math-anxious individuals when the probe appeared on the same location as the math-related prime. This suggests that math-anxious individuals paid more attention to math-related stimuli than non-math-anxious individuals, leading them to respond more quickly to the probes.

## Neural network modeling: prior relevant models

In this and the next section, we will attempt to provide an integrative neural network model of the cognitive and neural underpinning of mathematics anxiety. A neural network model is a computational system that is loosely based on a biological neural network (O'Reilly and Munakata, 2006; Moustafa and Maida, 2007; Moustafa et al., 2009, 2010, 2013a,b,c, 2017a,b; Moustafa and Gluck, 2011a,b; Helie et al., 2013; Muralidharan et al., 2014, 2016; Faghihi and Moustafa, 2015; Khalil et al., 2017, 2018; Moustafa, 2017; Chakravarthy and Moustafa, 2018). It performs mathematical calculations to simulate how brain processes work and is a tool used to test theories and suggest directions for future research (Moustafa, 2017; Chakravarthy and Moustafa, 2018).

Neural network modeling was used extensively to investigate the mechanisms of numerical cognition and cognitive control. For example, Verguts et al. (2005) implemented a neural network model that proposed a place-coding system to explain how number-selective neurons that are attuned to numbers (Nieder et al., 2002) are represented on a mental number line. Within the numerical cognition literature, the mental number line is a key hypothesis proposing that numbers are spatially located left or right on a visually perceived line (Dehaene, 2001). Verguts et al. (2005) model, called a model of exact small-number representation, simulated a symbolic number comparison task, which involved deciding which of two single-digit numbers has greatest magnitude. The numbers were presented as input to the model and were represented using place-coding characteristics where each number neuron activates maximally on the mental number line, and surrounding neurons activate with decreasing strength as they become further away. The model then activated either the left or right response unit, depending on which presented number was the largest. The model accounted for the numerical distance effect, which is a classical finding observed in number comparison tasks, where it is easier to compare two numbers and decide which is larger when the numbers are further apart than when they are closer together (Moyer and Landauer, 1967). For example, it is easier to compare the numbers 2 and 9 and decide which is larger, than to compare the numbers 5 and 6. Experimental studies showed that individuals high in mathematics anxiety have more pronounced distance effects than individuals low on mathematics anxiety (Maloney et al., 2011; Dietrich et al., 2015; Georges et al., 2016). Verguts et al. (2005) place-coding model was seminal in the development of computational models of numerical cognition and was the basis of subsequent neural network models simulating number magnitude comparison tasks (e.g. Van Opstal et al., 2008; Chen and Verguts, 2010).

Santens and Verguts (2011) adapted the Verguts et al. (2005) model to simulate the numerical Stroop task, which involved deciding which of two single-digit numbers had greater magnitude when they are presented in different physical sizes. Santens and Verguts (2011) proposed the shared decisions account where numerical and physical sizes are initially processed separately then interact at the decision level of the task. Moeller et al. (2011) also extended the Verguts et al. (2005) model and simulated a two-digit number comparison task, that is, deciding which of two two-digit numbers had the largest magnitude. Their model proposed a separate mental number line that is recycled for each place value. For example, both the 10s and 1s of a two-digit number are decomposed to their own mental number line, rather than the entire two-digit number holistically being represented on just one mental number line. The model consisted of a single-digit number comparison network for each of the 10s and 1s. Huber et al. (2013) extended their previous model to include the modeling of cognitive control. It was based on a neural network model by Verguts and Notebaert (2008) who proposed a conflict-modulated Hebbian learning rule to show how the cognitive control system knows where to intervene when it detects conflict. The Verguts and Notebaert (2008) model consisted of a conflict monitoring unit that monitored the amount of conflict in the system during a cognitive task and signaled to strengthen connections between active representations (thereby strengthening task-relevant associations) when conflict was encountered. By integrating their two-digit number comparison model with a cognitive control network, Huber et al. (2013) were able to model the conflict that occurs during a two-digit number comparison task, where the 10s are initially compared while ignoring the units. Subsequently, the model was extended to include number comparison of three-digit numbers (Huber et al., 2013) and decimals (Huber et al., 2014; Nuerkand Moeller, 2014). Eventually, all the models were integrated into one general framework for multi-symbol number comparison (Huber et al., 2016).

To our best knowledge, there is no model of mathematics anxiety. Rather, there were models in anxiety generally (Mkrtchian et al., 2017) or its effects on some specific processes such as decision making in language processes (Snyder et al., 2010). These models assume that anxiety leads to reduction of neural inhibition, making more neurons active, and leading to difficulty making a decision.

## An integrative neural network model of mathematics anxiety

Mathematics anxiety was primarily studied in behavioral experiments, and more recently by imaging and electrophysiological techniques, as described above. However, to our knowledge, there are no neural network modeling studies of mathematics anxiety. Therefore, we here provide a theoretical integrative neural network model on the relationship between mathematics anxiety and impairments in inhibition, attention, and working memory. Our theoretical model integrates and extends the general modeling framework by Huber and colleagues and Verguts and colleagues (Verguts et al., 2005; Huber et al., 2013, 2016). In our integrative model, we assume that normal mathematics processing and cognition involves several brain areas, including the basal ganglia, anterior cingulate, prefrontal cortex, and amygdala (Figure 2). Initially, perceptual input from sensory cortical areas is projected to several cortical and subcortical areas for further processing. Information maintained in the prefrontal's working memory aids the performance of mathematics activities via top-down effect on the basal ganglia (decision-making system). Our theoretical model can account for performance in the above-mentioned behavioral tasks such as the number comparison and numerical Stroop tasks. In these tasks, a response conflict will increase the activation in the anterior cingulate and amygdala, which then interferes with normal responses of the basal ganglia, via a top-down effect. In addition, the model can also account for individual differences in working memory performance, as these are related to prefrontal function and exert top-down effect on decision-making systems (e.g. the basal ganglia).

As discussed above, previous research showed that mathematics anxiety impacts several brain areas, including anterior cingulate cortex, prefrontal cortex, and the amygdala. According to our model (see Figure 2), mathematics anxiety increases the activation of the amygdala (leading to an increase in stress) and anterior cingulate cortex (leading to the perception of conflict), and impairs the prefrontal cortex' working memory mechanisms. These disruptions have top-down effects on the decision-making systems (e.g. the basal ganglia), leading to slow and incorrect responses in mathematics activities. In other words, stress experienced due to exposure of mathematics activities will increase the activity of the amygdala, which will, in turn, interfere with decision making, that is, performance in mathematics activities. According to this model, impaired performance in the numerical Stroop paradigm (described above) is possibly due to the over-activation of the anterior cingulate cortex, thus, affecting decision

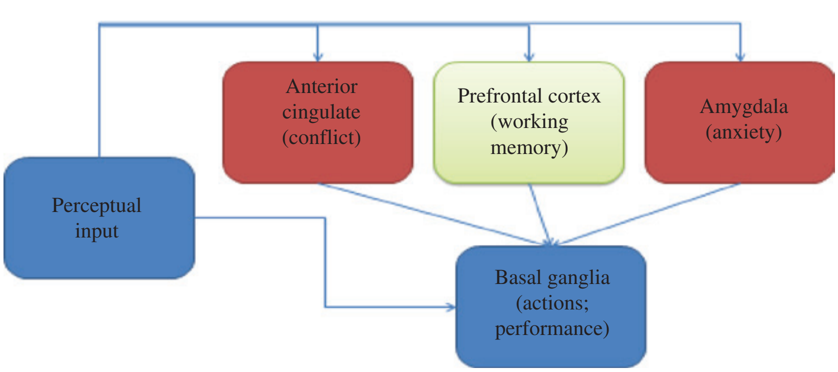


**Figure 2:** An integrative model of the effect of mathematics anxiety on the brain.
A red-colored brain area refers to overactivation, while a green-colored refers to underactivation, due to mathematics anxiety.

making and performance in mathematics activities via a top-down mechanism. Similarly, disruption to prefrontal's working memory mechanisms due to the exposure of hard mathematics problems could also impact the performance of mathematics activities via a top-down mechanism.

## Discussion and future directions

Anxiety about performing mathematics is an increasingly important issue (OECD, 2013). In 2012, around 30% of 15-year-old students across OECD countries reported feeling helpless or nervous when solving a mathematics problem, and 59% reported they worry about mathematics classes being difficult. Furthermore, a position paper released by the Australian Government's Office of the Chief Scientist (2015) discusses the importance of education in science, technology, engineering, and mathematics (STEM), suggesting students will enter a very different work force in 2030. Given the importance of mathematical skills, understanding and treating mathematics anxiety is essential in helping to reduce students' emotional stress and improving education outcomes around the subject.

Studies also show that individuals with mathematics learning disability show mathematics anxiety (Carey et al., 2015). Mathematics learning disability is a condition related to difficulty in understanding numbers (Mazzocco et al., 2011; Soares et al., 2018). Future work should provide a computational model of the cognitive and neural mechanisms in individuals with mathematics learning disability. Future work should also explain how changing different model parameters can help explain math performance and anxiety in individuals with mathematics learning disability. As no studies to date examined mathematics anxiety using neural network modeling, it is our hope that this paper will open a new field of enquiry on the topic using this method as an adjunct to behavioral experiments. Although it is known that mathematics anxiety impairs cognition, its underlying mechanism is not well understood. This paper provides an integrative network model to explain the effects of mathematics anxiety on the brain and cognition. Using neural network modeling, future work can test theories linking anxiety and cognitive performance in the context of mathematics anxiety. The results can provide indications as to how the underlying mechanisms affected by mathematics anxiety are consistent with research findings of other anxiety disorders, as discussed above. Additionally, by exploring the effect of changing the activation levels of different parts of the neural network model (as shown in Figure 2), future work should examine how mathematics anxiety impacts the brain and cognition, and can discover other underlying factors related to mathematics anxiety. Predictions can then be made to direct future research. Understanding the underlying cognitive mechanisms that are impaired can aid psychologists and educators in developing tests to identify mathematics learning difficulties early in children, and introduce targeted intervention strategies and teaching methods to prevent students developing mathematics anxiety or help those already affected by it.

## References

Akirav, I. and Maroun, M. (2007). The role of the medial prefrontal cortex-amygdala circuit in stress effects on the extinction of fear. Neural. Plast. *2007*, 30873.

Arsalidou, M., Pawliw-Levac, M., Sadeghi, M., and Pascual-Leone, J. (2018). Brain areas associated with numbers and calculations in children: meta-analyses of fMRI studies. Dev. Cogn. Neurosci. *30*, 239–250.

Artemenko, C., Daroczy, G., and Nuerk, H.C. (2015). Neural correlates of math anxiety – an overview and implications. Front. Psychol. *6*, 1333.

Ashcraft, M.H. (2002). Math anxiety: personal, educational, and cognitive consequences. Curr. Dir. Psychol. Sci. *11*, 181–185.

Ashcraft, M.H. and Faust, M.W. (1994). Mathematics anxiety and mental arithmetic performance: an exploratory investigation. Cogn. Emot. *8*, 97–125.

Ashcraft, M.H. and Kirk, E.P. (2001). The relationships among working memory, math anxiety, and performance. J. Exp. Psychol. Gen. *130*, 224–237.

Ashcraft, M.H. and Krause, J.A. (2007). Working memory, math performance, and math anxiety. Psychon. Bull. Rev. *14*, 243–248.

Ashcraft, M.H. and Ridley, K.S. (2005). Math anxiety and its cognitive consequences: a tutorial review. In J.I.D. Campbell (Ed.), Handbook of Mathematical Cognition (New York, NY: Psychology Press). pp. 315–325.

Baddeley, A. (1992). Working memory. Science *255*, 556–559.

Baloglu, M. (1999). A comparison of mathematics anxiety and statistics anxiety in relation to general anxiety. Inf. Anal. *85*, 1–30.

Beilock, S.L. (2008). Math performance in stressful situations. Curr. Dir. Psychol. Sci. *17*, 339–343.

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.

Besner, D. and Coltheart, M. (1979). Ideographic and alphabetic processing in skilled reading of English. Neuropsychologia *17*, 467–472.

Blair, K., Shaywitz, J., Smith, B.W., Rhodes, R., Geraci, M., Jones, M., McCaffrey, D., Vythilingam, M., Finger, E., Mondillo, K., et al. (2008). Response to emotional expressions in generalized social phobia and generalized anxiety disorder: evidence for separate disorders. Am. J. Psychiatry *165*, 1193–1202.

Botvinick, M.M., Braver, T.S., Barch, D.M., Carter, C.S., and Cohen, J.D. (2001). Conflict monitoring and cognitive control. Psychol. Rev. *108*, 624–652.

Braham, E.J. and Libertus, M.E. (2018). When approximate number acuity predicts math performance: the moderating role of math anxiety. PLoS One *13*, e0195696.
Braver, T.S. (2012). The variable nature of cognitive control: a dual mechanisms framework. Trends Cogn. Sci. *16*, 106–113.
Braver, T.S., Paxton, J.L., Locke, H.S., and Barch, D.M. (2009). Flexible neural mechanisms of cognitive control within human prefrontal cortex. Proc. Natl. Acad. Sci. U.S.A. *106*, 7351–7356.
Bull, R. and Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: inhibition, switching, and working memory. Dev. Neuropsychol. *19*, 273–293.
Carey, E., Hill, F., Devine, A., and Szucs, D. (2015). The chicken or the egg? The direction of the relationship between mathematics anxiety and mathematics performance. Front. Psychol. *6*, 1987.
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.
Chakravarthy, S. and Moustafa, A.A. (2018). Computational Neuroscience Models of the Basal Ganglia. (Singapore: Springer). https://doi.org/doi:10.1007/978-981-10-8494-2.
Chang, H., Sprute, L., Maloney, E.A., Beilock, S.L., and Berman, M.G. (2017). Simple arithmetic: not so simple for highly math anxious individuals. Soc. Cogn. Affect. Neurosci. *12*, 1940–1949.
Chipman, S.F., Krantz, D.H., and Silver, R. (1992). Mathematics anxiety and science careers among able college women. Psychol. Sci. *3*, 292–296.
Dehaene, S. (2001). Précis of the number sense. Mind Lang. *16*, 16–36.
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.
Dowker, A., Sarkar, A., and Looi, C.Y. (2016). Mathematics anxiety: what have we learned in 60 years? Front. Psychol. *7*, 508.
Dreger, R.M. and Aiken, L.R. (1957). The identification of number anxiety in a college population. J. Educ. Psychol. *48*, 344–351.
Evans, K.C., Wright, C.I., Wedig, M.M., Gold, A.L., Pollack, M.H., and Rauch, S.L. (2008). A functional MRI study of amygdala responses to angry schematic faces in social anxiety disorder. Depress. Anxiety *25*, 496–505.
Eysenck, M.W. and Calvo, M.G. (1992). Anxiety and performance: the processing efficiency theory. Cogn. Emot. *6*, 409–434.
Eysenck, M.W., Derakshan, N., Santos, R., and Calvo, M.G. (2007). Anxiety and cognitive performance: attentional control theory. Emotion *7*, 336–353.
Faghihi, F. and Moustafa, A.A. (2015). The dependence of neuronal encoding efficiency on Hebbian plasticity and homeostatic regulation of neurotransmitter release. Front. Cell. Neurosci. *9*, 164.
Faust, M.W., Ashcraft, M.H., and Fleck, D.E. (1996). Mathematics anxiety effects in simple and complex addition. Math. Cogn. *2*, 25–62.
Ganella, D.E., Barendse, M.E.A., Kim, J.H., and Whittle, S. (2017). Prefrontal-amygdala connectivity and state anxiety during fear extinction recall in adolescents. Front. Hum. Neurosci. *11*, 587.
Georges, C., Hoffmann, D., and Schiltz, C. (2016). How math anxiety relates to number-space associations. Front. Psychol. *7*, 1401.
Gold, A.L., Shechner, T., Farber, M.J., Spiro, C.N., Leibenluft, E., Pine, D.S., and Britton, J.C. (2016). Amygdala-cortical connectivity: associations with anxiety, development, and threat. Depress. Anxiety *33*, 917–926.
Guyer, A.E., Lau, J.Y., McClure-Tone, E.B., Parrish, J., Shiffrin, N.D., Reynolds, R.C., Chen, G., Blair, R.J., Leibenluft, E., Fox, N.A., et al. (2008). Amygdala and ventrolateral prefrontal cortex function during anticipated peer evaluation in pediatric social anxiety. Arch. Gen. Psychiatry *65*, 1303–1312.
Heaton, S.K., Chelune, G.J., Talley, J.L., Kay, G.G., and Curtiss, G. (1993). Wisconsin Card Sorting Test Manual: Revised and Expanded (Odessa, FL: Psychological Assessment Resources).
Helie, S., Chakravarthy, S., and Moustafa, A.A. (2013). Exploring the cognitive and motor functions of the basal ganglia: an integrative review of computational cognitive neuroscience models. Front. Comput. Neurosci. *7*, 174.
Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. J. Res. Math. Educ. *21*, 33–46.
Holmes, J. and Gathercole, S.E. (2014). Taking working memory training from the laboratory into schools. Educ. Psychol. (Lond.) *34*, 440–450.
Hopko, D.R., Ashcraft, M.H., Gute, J., Ruggiero, K.J., and Lewis, C. (1998). Mathematics anxiety and working memory: support for the existence of a deficient inhibition mechanism. J. Anxiety Disord. *12*, 343–355.
Hopko, D.R., McNeil, D.W., Gleason, P.J., and Rabalais, A.E. (2002). The emotional Stroop paradigm: performance as a function of stimulus properties and self-reported mathematics anxiety. Cognit. Ther. Res. *26*, 157–166.
Huber, S., Moeller, K., Nuerk, H.C., Macizo, P., Herrera, A., and Willmes, K. (2013). Cognitive control in number processing: a computational model. In: The 12th International Conference on Cognitive Modeling (Ottawa, Canada).
Huber, S., Klein, E., Willmes, K., Nuerk, H.C., and Moeller, K. (2014). Decimal fraction representations are not distinct from natural number representations – evidence from a combined eye-tracking and computational modeling approach. Front. Hum. Neurosci. *8*, 172.
Huber, S., Nuerk, H.C., Willmes, K., and Moeller, K. (2016). A general model framework for multisymbol number comparison. Psychol. Rev. *123*, 667–695.
Hutchison, K.A. (2011). The interactive effects of listwide control, item-based control, and working memory capacity on Stroop performance. J. Exp. Psychol. *37*, 851–860.
Julio-Costa, A., Martins, A.A.S., Wood, G., de Almeida, M.P., de Miranda, M., Haase, V.G., and Carvalho, M.R.S. (2019). Heterosis in COMT Val158Met polymorphism contributes to sex-differences in children's math anxiety. Front. Psychol. *10*, 1013.
Kazelskis, R., Reeves, C., Kersh, M.E., Bailey, G., Cole, K., and Larmon, M. (2000). Mathematics anxiety and test anxiety: separate constructs? J. Exp. Educ. *68*, 137–146.
Khalil, R., Moftah, M.Z., and Moustafa, A.A. (2017). The effects of dynamical synapses on firing rate activity: a spiking neural network model. Eur. J. Neurosci. *46*, 2445–2470.
Khalil, R., Karim, A.A., Khedr, E., Moftah, M., and Moustafa, A.A. (2018). Dynamic Communications between $GABA_A$switch, local connectivity, and synapses during cortical development: a computational study. Front. Cell. Neurosci. *12*, 468.
Klados, M.A., Simos, P., Micheloyannis, S., Margulies, D., and Bamidis, P.D. (2015). ERP measures of math anxiety: how math anxiety affects working memory and mental calculation tasks? Front. Behav. Neurosci. *9*, 282.
Kucian, K., McCaskey, U., O'Gorman Tuura, R., and von Aster, M. (2018). Neurostructural correlate of math anxiety in the brain of children. Transl. Psychiatry *8*, 273.
Lamichhane, B., McDaniel, M.A., Waldum, E.R., and Braver, T.S. (2018). Age-related changes in neural mechanisms of prospective memory. Cognit. Affect. Behav. Neurosci. *18*, 982–999.

Lauer, J.E., Esposito, A.G., and Bauer, P.J. (2018). Domain-specific anxiety relates to children's math and spatial performance. Dev. Psychol. *54*, 2126–2138.
Liu, J., Li, J., Peng, W., Feng, M., and Luo, Y. (2019). EEG correlates of math anxiety during arithmetic problem solving: implication for attention deficits. Neurosci. Lett. *703*, 191–197.
Lukasik, K.M., Waris, O., Soveri, A., Lehtonen, M., and Laine, M. (2019). The relationship of anxiety and stress with working memory performance in a large non-depressed sample. Front. Psychol. *10*, 4.
Lukowski, S.L., DiTrapani, J., Rockwood, N.J., Jeon, M., Thompson, L.A., and Petrill, S.A. (2019a). Etiological distinction across dimensions of math anxiety. Behav. Genet. *49*, 310–316.
Lukowski, S.L., DiTrapani, J.B., Jeon, M., Wang, Z., Schenker, V.J., Doran, M.M., Hart, S.A., Mazzocco, M.M.M., Willcutt, E.G., Thompson, L.A., et al. (2019b). Multidimensionality in the measurement of math-specific anxiety and its relationship with mathematical performance. Learn. Individ. Differ. *70*, 228–235.
Luttenberger, S., Wimmer, S., and Paechter, M. (2018). Spotlight on math anxiety. Psychol. Res. Behav. Manag. *11*, 311–322.
Lyons, I.M. and Beilock, S.L. (2012). Mathematics anxiety: separating the Math from the anxiety. Cereb. Cortex *22*, 2102–2110.
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. (Hove) *64*, 10–16.
Maloney, E.A., Schaeffer, M.W., and Beilock, S.L. (2013). Mathematics anxiety and stereotype threat: shared mechanisms, negative consequences and promising interventions. Res. Math. Educ. *15*, 115–128.
Mattarella-Micke, A., Mateo, J., Kozak, M.N., Foster, K., and Beilock, S.L. (2011). Choke or thrive? The relation between salivary cortisol and math performance depends on individual differences in working memory and math-anxiety. Emotion *11*, 1000–1005.
Mazzocco, M.M., Feigenson, L., and Halberda, J. (2011). Impaired acuity of the approximate number system underlies mathematical learning disability (dyscalculia). Child Dev. *82*, 1224–1237.
McClure, E.B., Monk, C.S., Nelson, E.E., Parrish, J.M., Adler, A., Blair, R.J., Fromm, S., Charney, D.S., Leibenluft, E., Ernst, M., et al. (2007). Abnormal attention modulation of fear circuit function in pediatric generalized anxiety disorder. Arch. Gen. Psychiatry *64*, 97–106.
Meyer, M., Salimpoor, V., Wu, S., Geary, D., and Menon, V. (2010). Differential contribution of specific working memory components to mathematics achievement in 2nd and 3rd graders. Learn. Individ. Differ. *20*, 101–109.
Milad, M.R., Quinn, B.T., Pitman, R.K., Orr, S.P., Fischl, B., and Rauch, S.L. (2005). Thickness of ventromedial prefrontal cortex in humans is correlated with extinction memory. Proc. Natl. Acad. Sci. U.S.A. *102*, 10706–10711.
Milad, M.R., Pitman, R.K., Ellis, C.B., Gold, A.L., Shin, L.M., Lasko, N.B., Zeidan, M.A., Handwerger, K., Orr, S.P., and Rauch, S.L. (2009). Neurobiological basis of failure to recall extinction memory in posttraumatic stress disorder. Biol. Psychiatry *66*, 1075–1082.
Mkrtchian, A., Aylward, J., Dayan, P., Roiser, J.P., and Robinson, O.J. (2017). Modeling avoidance in mood and anxiety disorders using reinforcement learning. Biol. Psychiatry *82*, 532–539.
Moeller, K., Huber, S., Nuerk, H.C., and Willmes, K. (2011). Two-digit number processing: holistic, decomposed or hybrid? A computational modelling approach. Psychol. Res. *75*, 290–306.
Monk, C.S., Telzer, E.H., Mogg, K., Bradley, B.P., Mai, X., Louro, H.M., Chen, G., McClure-Tone, E.B., Ernst, M., and Pine, D.S. (2008). Amygdala and ventrolateral prefrontal cortex activation to masked angry faces in children and adolescents with generalized anxiety disorder. Arch. Gen. Psychiatry *65*, 568–576.
Morsanyi, K., Busdraghi, C., and Primi, C. (2014). Mathematical anxiety is linked to reduced cognitive reflection: a potential road from discomfort in the mathematics classroom to susceptibility to biases. Behav. Brain Funct. *10*, 31.
Moustafa, A.A. (2017). Computational Models of Brain and Behavior (Wiley-Blackwell).
Moustafa, A.A. and Maida, A.S. (2007). Using TD learning to simulate working memory performance in a model of the prefrontal cortex and basal ganglia. Cogn. Syst. Res. *8*, 262–281.
Moustafa, A.A. and Gluck, M.A. (2011a). Computational cognitive models of prefrontal-striatal-hippocampal interactions in Parkinson's disease an schizophrenia. Neural Netw. *24*, 575–591.
Moustafa, A.A. and Gluck, M.A. (2011b). A neurocomputational model of dopamine and prefrontal-striatal interactions during multicue category learning by Parkinson patients. J. Cogn. Neurosci. *23*, 151–167.
Moustafa, A.A., Myers, C.E., and Gluck, M.A. (2009). A neurocomputational model of classical conditioning phenomena: a putative role for the hippocampal region in associative learning. Brain Res. *1276*, 180–195.
Moustafa, A.A., Keri, S., Herzallah, M.M., Myers, C.E., and Gluck, M.A. (2010). A neural model of hippocampal-striatal interactions in associative learning and transfer generalization in various neurological and psychiatric patients. Brain Cogn. *74*, 132–144.
Moustafa, A.A., Gilbertson, M.W., Orr, S.P., Herzallah, M.M., Servatius, R.J., and Myers, C.E. (2013a). A model of amygdala-hippocampal-prefrontal interaction in fear conditioning and extinction in animals. Brain Cogn. *81*, 29–43.
Moustafa, A.A., Herzallah, M.M., and Gluck, M.A. (2013b). Dissociating the cognitive effects of levodopa versus dopamine agonists in a neurocomputational model of learning in Parkinson's disease. Neurodegener. Dis. *11*, 102–111.
Moustafa, A.A., Wufong, E., Servatius, R.J., Pang, K.C., Gluck, M.A., and Myers, C.E. (2013c). Why trace and delay conditioning are sometimes (but not always) hippocampal dependent: a computational model. Brain Res. *1493*, 48–67.
Moustafa, A.A., Misiak, B., and Frydecka, D. (2017a). Computational models of schizophrenia. In: Computational models of Brain and Behavior. A.A. Moustafa, ed. (Hoboken, NJ: Wiley-Blackwell).
Moustafa, A.A., Tindle, R., Ansari, Z., Doyle, M.J., Hewedi, D.H., and Eissa, A. (2017b). Mathematics, anxiety, and the brain. Rev. Neurosci. *28*, 417–429.
Moyer, R.S. and Landauer, T.K. (1967). Time required for judgements of numerical inequality. Nature *215*, 1519–1520.
Muralidharan, V., Balasubramani, P.P., Chakravarthy, V.S., Lewis, S.J., and Moustafa, A.A. (2014). A computational model of altered gait patterns in parkinson's disease patients negotiating narrow doorways. Front. Comput. Neurosci. *7*, 190.
Muralidharan, V., Balasubramani, P.P., Chakravarthy, V.S., Gilat, M., Lewis, S.J., and Moustafa, A.A. (2016). A neurocomputational model of the effect of cognitive load on freezing of gait in Parkinson's disease. Front. Hum. Neurosci. *10*, 649.
Nieder, A., Freedman, D.J., and Miller, E.K. (2002). Representation of the quantity of visual items in the primate prefrontal cortex. Science *297*, 1708–1711.

O'Reilly, R.C. and Munakata, Y. (2006). Computational neuroscience: from biology to cognition. Encyclopedia of Cognitive Science (Hoboken, NJ: Wiley).

OECD. (2013). PISA 2012 Results: Ready to Learn: Students' Engagement, Drive and Self-Beliefs (Volume III) (Paris, France: Author). https://doi.org/10.1787/9789264201170-en.

Office of the Chief Scientist. (2015). Transforming STEM teaching in Australian primary schools: everybody's business. Retrieved from http://www.chiefscientist.gov.au/wp-content/uploads/Transforming-STEM-teaching_FINAL.pdf.

Packiam Alloway, T., Banner, G.E., and Smith, P. (2010). Working memory and cognitive styles in adolescents' attainment. Br. J. Educ. Psychol. *80*, 567–581.

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.

Pillay, S.S., Rogowska, J., Gruber, S.A., Simpson, N., and Yurgelun-Todd, D.A. (2007). Recognition of happy facial affect in panic disorder: an fMRI study. J. Anxiety Disord. *21*, 381–393.

Raghubar, K.P., Barnes, M.A., and Hecht, S.A. (2010). Working memory and mathematics: a review of developmental, individual difference, and cognitive approaches. Learn. Individ. Differ. *20*, 110–122.

Ramirez, G., Gunderson, E.A., Levine, S.C., and Beilock, S.L. (2013). Math anxiety, working memory, and math achievement in early elementary school. J. Cogn. Dev. *14*, 187–202.

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.

Rubinsten, O., Eidlin, H., Wohl, H., and Akibli, O. (2015). Attentional bias in math anxiety. Front. Psychol. *6*, 1539.

Sakai, Y., Kumano, H., Nishikawa, M., Sakano, Y., Kaiya, H., Imabayashi, E., Ohnishi, T., Matsuda, H., Yasuda, A., Sato, A., et al. (2005). Cerebral glucose metabolism associated with a fear network in panic disorder. Neuroreport *16*, 927–931.

Sanchez-Perez, N., Castillo, A., Lopez-Lopez, J.A., Pina, V., Puga, J.L., Campoy, G., Gonzalez-Salinas, C., and Fuentes, L.J. (2017). Computer-based training in math and working memory improves cognitive skills and academic achievement in primary school children: behavioral results. Front. Psychol. *8*, 2327.

Santens, S. and Verguts, T. (2011). The size congruity effect: Is bigger always more? Cognition *118*, 94–110.

Schaeffer, M.W., Rozek, C.S., Berkowitz, T., Levine, S.C., and Beilock, S.L. (2018). Disassociating the relation between parents' math anxiety and children's math achievement: long-term effects of a math app intervention. J. Exp. Psychol. Gen. *147*, 1782–1790.

Skagerlund, K., Ostergren, R., Vastfjall, D., and Traff, U. (2019). How does mathematics anxiety impair mathematical abilities? Investigating the link between math anxiety, working memory, and number processing. PLoS One *14*, e0211283.

Snyder, H.R., Hutchison, N., Nyhus, E., Curran, T., Banich, M.T., O'Reilly, R.C., and Munakata, Y. (2010). Neural inhibition enables selection during language processing. Proc. Natl. Acad. Sci. U.S.A. *107*, 16483–16488.

Soares, N., Evans, T., and Patel, D.R. (2018). Specific learning disability in mathematics: a comprehensive review. Transl. Pediatr. *7*, 48–62.

Sokolowski, H.M. and Necka, E.A. (2016). Remediating math anxiety through cognitive training: potential roles for math ability and social context. J. Neurosci. *36*, 1439–1441.

Soltanlou, M., Artemenko, C., Dresler, T., Fallgatter, A.J., Ehlis, A.C., and Nuerk, H.C. (2019). Math anxiety in combination with low visuospatial memory impairs math learning in children. Front. Psychol. *10*, 89.

Stroop, J.R. (1935). Studies of interference in serial verbal reactions. J. Exp. Psychol. *18*, 643–662.

Suarez-Pellicioni, M., Nunez-Pena, M.I., and Colome, A. (2013). Abnormal error monitoring in math-anxious individuals: evidence from error-related brain potentials. PLoS One *8*, e81143.

Suarez-Pellicioni, M., Nunez-Pena, M.I., and Colome, A. (2014). Reactive recruitment of attentional control in math anxiety: an ERP study of numeric conflict monitoring and adaptation. PLoS One *9*, e99579.

Suarez-Pellicioni, M., Nunez-Pena, M.I., and Colome, A. (2015). Attentional bias in high math-anxious individuals: evidence from an emotional Stroop task. Front. Psychol. *6*, 1577.

Suarez-Pellicioni, M., Nunez-Pena, M.I., and Colome, A. (2016). Math anxiety: a review of its cognitive consequences, psychophysiological correlates, and brain bases. Cogn. Affect. Behav. Neurosci. *16*, 3–22.

Takeuchi, H., Taki, Y., and Kawashima, R. (2010). Effects of working memory training on cognitive functions and neural systems. Rev. Neurosci. *21*, 427–450.

Tillfors, M., Furmark, T., Marteinsdottir, I., Fischer, H., Pissiota, A., Langstrom, B., and Fredrikson, M. (2001). Cerebral blood flow in subjects with social phobia during stressful speaking tasks: a PET study. Am. J. Psychiatry *158*, 1220–1226.

van den Heuvel, O.A., Veltman, D.J., Groenewegen, H.J., Witter, M.P., Merkelbach, J., Cath, D.C., van Balkom, A.J., van Oppen, P., and van Dyck, R. (2005). Disorder-specific neuroanatomical correlates of attentional bias in obsessive-compulsive disorder, panic disorder, and hypochondriasis. Arch. Gen. Psychiatry *62*, 922–933.

Van Mier, H.I., Schleepen, T.M.J., and Van den Berg, F.C.G. (2018). Gender differences regarding the impact of math anxiety on arithmetic performance in second and fourth graders. Front. Psychol. *9*, 2690.

Verguts, T. and Notebaert, W. (2008). Hebbian learning of cognitive control: dealing with specific and nonspecific adaptation. Psychol. Rev. *115*, 518–525.

Verguts, T., Fias, W., and Stevens, M. (2005). A model of exact small-number representation. Psychon. Bull. Rev. *12*, 66–80.

Vytal, K.E., Cornwell, B.R., Letkiewicz, A.M., Arkin, N.E., and Grillon, C. (2013). The complex interaction between anxiety and cognition: insight from spatial and verbal working memory. Front Hum Neurosci *7*, 93.

Witt, M. (2011). School based working memory training: preliminary finding of improvement in children's mathematical performance. Adv. Cogn. Psychol. *7*, 7–15.

Wu, S.S., Willcutt, E.G., Escovar, E., and Menon, V. (2014). Mathematics achievement and anxiety and their relation to internalizing and externalizing behaviors. J. Learn. Disabil. *47*, 503–514.

Young, C.B., Wu, S.S., and Menon, V. (2012). The neurodevelopmental basis of math anxiety. Psychol. Sci. *23*, 492–501.