Prepublication copy of Chapter 8 in:

Mathematics Anxiety: What is Known and What is Still to be Understood

2019

Taylor & Francis

Edited by Irene C. Mammarella, Sara Caviola and Ann Dowker

Chapter 8

Math Anxiety in children with and without mathematical difficulties:

The role of gender and genetic factors

Sara Caviola[1], Irene C. Mammarella[2], Yulia Kovas[3]

[1] Centre for Neuroscience in Education of Cambridge University (UK)

[2] Department of Developmental and Social Psychology, University of Padova (Italy)

[3] Department of Psychology, Goldsmiths University of London (UK)

Mathematics anxiety is generally defined as feeling tense, fearful and apprehensive about mathematics (Richardson & Suinn, 1972). Itis a multi-dimensional construct,characterized by different types of reactions: emotional (i.e., negative feelings); cognitive (e.g., intrusive concerns and thoughts); physiological (e.g., increased arousal, stress and agitation); and behavioural (e.g., avoiding contexts that require the use of mathematical skills, disengagement and off-task behaviours).From a different angle, math anxiety can generate reverse effect than positive factors, such as as interest toward mathematics and self-efficacy (Moore, Rudig & Ashcraft, 2014). Individuals with high levels of math anxiety tend to take fewer mathematics courses; gain lower grades in those they do attend; and avoid, where possible, additional maths classes (Ashcraft, 2002).In addition, highly math-anxious students are also more likely to avoid mathematically-oriented college majors and career paths that require quantitative skills (Ashcraft, Krause, & Hopko, 2007; Ashcraft & Moore, 2009).Math anxietyseems to have serious long-term consequences, adversely influencing an individual's choice of career, type of occupation, and professional growth in adulthood (Ashcraft & Ridley, 2005; Beasley, Long & Natali, 2001; Hembree, 1990; Ho et al., 2000). Beyond consequences for an individual's personal life, math anxietyalso affects society. For example, in the USA math anxietymay contribute to the shortage of graduates, who want to work in the area of science, technology, engineering and mathematics-for the demands of a technology-dependent society -despite increased emphasis on improving mathematical education (Beilock & Maloney, 2015).

Because of its consequences in limiting people's mastery of mathematics,math anxietyhas become a subject of increasing interest in educational, rather than only clinical settings. Many factors are involved in the links between math anxietyand mathematics.For example, these links depend on the nature of mathematics, such as increasing complexity of its contents during the school-years.In the following sections,we summarize previous studies ofmath anxiety, focusingon gender differences,distinction between mathematics difficulties related to math anxietyvs those related to specific mathematics impairments, and the role of geneticfactors.

Gender differences in Math anxiety and Mathematics performance

Math anxietyhas recently been investigated in the best-known international comparison of student achievement in mathematics, the Programme for International Student Assessment (PISA, OECD, 2013), which assessed the competencies of 15-year-olds students from 65 different countries. The PISA investigation (OECD, 2013) asked students several questions about math anxiety, such as whether they get very tense or nervous when they have to do mathematics homework or mathematics problems. A considerable proportion of studentsreported feelings of helplessness and emotional stress when dealing with mathematics. Across OECD countries, around 33% reported that they get very tense when they have to do mathematics homework; 31% - that they get very nervous doing mathematics problems, and 61% - that they worry about getting poor grades in mathematics. The proportion of students who reported high math anxietyhas slightly increased from 2003 (29%) to 2012 (32%). Across most countries, differences in levels of mathematics anxiety related to gender are wide, with girls on average reporting higher math anxietythan boys. For example, Italian girls on average reported being less confident in their ability to learn mathematics, and more anxious about mathematics than boys (e.g., 48.5% of the girls vs 37.8% of the boys reported high levels of math anxiety; OECD, 2013). A similar trend could be observed for the UK adolescents (although the overall level of math anxietywas lower than in the Italian sample): 24.4% of the girls vs. 15% of the boys reported high levels of math anxiety. Across most countries, students who reported higher math anxietyhad poorer performance in mathematics than students who reported lower levels of math anxiety(Foley et al., 2017).

Several conclusions about math anxietycan be drawn from the existing literature. Similar findings to those observed in the PISA survey (OECD, 2013), have been reported in other studies. First, the phenomenon of math anxietyhas been observed in in both western and eastern countries (Ching, 2017; Ho et al., 2000; Lee, 2009). Second, math anxietyis robustly negatively correlated with mathematics performance,in both boys and girls (roughly$r$ = -.30; Hembree, 1990; Ma, 1999). Third, the negative relation between math anxietyandmathematics performance seems to be stronger in girls than in boys (Else-Quest, Hyde, & Linn, 2010;Devine, Fawcett, Szűcs, & Dowker, 2012; Dowker, Sarkar, & Looi, 2016; Hill et al., 2016).Indeed, females, on average, have higher levels of math anxietythan males (Hembree, 1990; Karimi & Venkatesan, 2009), and this gender difference seems to increase in older students (Hill, et al. 2016).

However, gender differences in mathematics performance and math anxietyseem to follow different trends. Recent studies revealed that gender-gap in maths performances is disappearing. For example, the study of Karimi and Venkatesan (2009) did not show gender differences in mathematics performance. Similarly, Devine and colleagues (2012), found no differences in maths performance between girls and boys in 482 students attending secondary school in UK. However, the same study reported significant differences between math anxietyin girls and boys. Similar findings, i.e., no gender differences in mathematics but in math anxiety, have been observed in a sample of 981 primary and middle schools-students in Italy (Hill, et al. 2016).

Althoughseveralcross-sectional studies found no gender differences in math anxiety (e.g., (Ahmed, 2018; Birgin, Baloğlu, Çatlıoğlu, & Gürbüz, 2010; Chiu & Henry, 1990; Newstead, 1998), a recent meta-analysis found that girls reported significantly higher math anxiety than boys despite negligible gender differences in mathematics performance (Else-Quest et al. 2010).It is worth noting though not every of these studies took into account an objectivemeasure of mathematics performance (i.e., Ahmed, 2018).Different hypotheses have been proposed. Apossible explanation for similar performance in mathematics between boys and girls, despite greater math anxiety in girls is that girls may have greater mathematics potential than boys (Devine et al. 2012). Alternatively, greater math anxiety in girls may relate to their lower maths self-perceptions and confidence (Cvencek, Meltzoff, & Kapur, 2014; Fredricks &Eccles, 2002; Marsh & Yeung, 1998; Pajares, 2005); the fact that boys are less afraid to openly state their negative feelings (Ashcraft & Ridley, 2005); or that boys' answers are more affected by a recall bias as well as social desirability biases (Dowker et al. 2016); or the presence of gender stereotypes about maths (Appel, Kronberger, & Aronson, 2011; Flore & Wicherts, 2015). More research is needed in order to clarify why female students frequently report higher math anxiety than do male students.

Mathematics anxiety vs. Mathematical difficulties

A large proportionof students have cognitive and/oremotional difficulties in dealing with mathematics (Hopko, McNeil, Gleason, & Rabalais, 2002). There are two major reasons for why a student fails in mathematics: thepresence of a specific learning disorder in mathematics (i.e., developmentaldyscalculia), or the presence of emotional issues thataffect mathematicsperformance, such as MA.

An unresolved question is whether MA causes poor mathematics performance, or whether poor mathematics performance prompts MA(Carey, Hill, Devine, & Szücs, 2016). According to some studies, MA is believed to cause negative thoughts andruminations, often about the consequences of failure in maths tasks(Ashcraft & Kirk, 2001). Thus, cognitive resources, such as working memory, that are needed for successin mathematics, are impaired in individuals with high math anxiety (Ashcraft & Kirk, 2001; Ashcraft & Faust, 1994). In contrast, other authors argue that math anxiety is actually the outcome of poormathematicsperformance. According tothis account, a student's reduced competency in maths leads to weakerlearning and performance, whichthen contribute to the development ofmath anxiety (Maloney, 2016). Math anxiety is thus an outcome of poor mathematics skills. Another proposed framework within this account, suggests that students who havereduced maths abilities avoid taking maths classes and learning mathematics in general. This avoidance can contribute tosuccessive failures and lead to the development ofmath anxiety. Consistent with this claim, students with high math anxiety take fewer maths courses (Ashcraft & Kirk,2001; Hembree, 1988; LeFevre, Kulak, & Heymans, 1992).

Thus, students with high math anxiety or with mathematics difficulties due to the presence of a specific learning disorder can be confused, or from another viewpoint, it can be expected that math anxiety will be frequently comorbid with developmental dyscalculia.This is actually one important question that is needed to be further addressed in future research:do mathematical difficulties and math anxiety share a common core in terms of impairments or can be identified as two separate and dissociable problems?

Developmental dyscalculia is a specific learning disorder of mathematical ability in individuals showing average language and general cognitive skills(Devine, Soltész, Nobes, Goswami, & Szűcs, 2013; Shalev & Gross-Tsur, 2001). Not much research to date has investigated the prevalence of co-occurrence between math anxiety and dyscalculia.Recently, Devine, Hill, Carey, and Szűcs, (2018)investigated comorbidity these conditions in a sample of 1757 primary and secondary school childrenin UK.The results demonstratedthat developmental dyscalculia and math anxiety largely dissociate, calling into question the idea that low mathematicsperformance is the primary cause of math anxiety.In particular, Devine and colleagues (2018) showed that using a threshold ofhigh math anxiety at or above the 90th percentile, 10% of students with typicalmathematics performance had high math anxiety; and 22% percent ofstudents in the developmental dyscalculia had high math anxiety. The study also reported an equal distribution of boys and girls with developmental dyscalculia, in agreement with previous findings(Koumoula et al., 2004; Lewis, Hitch, & Walker, 1994). In contrast, Devine and co-authors (2018) showed that more females than males fell in the sub-group with co-morbid developmental dyscalculia and math anxiety. which, again, is in line withfindingsreporting higher math anxiety in girls compared to boys (reviewed in Devine et al., 2012, and Hill et al., 2016; for opposite results, see: Kucian et al., 2018). In another study,the prevalence of developmental dyscalculia was the same in boys and girls; however,gender differences emerged when the cut-off criteria was varied using a discrepancy threshold between reading and mathematics performances (Devine, et al. 2013). In other words, there were more girls with higher reading than mathematics performances, but when performances on maths were below 1 or 1.5 SD (with average or above average reading skills), no differences between boys and girls emerged.

Some previous studies have also examined the cognitive consequences of math anxiety, by comparing high-vs-low math anxiety levels in different mathematics achievement groups (e.g., (Lai, Zhu, Chen, & Li, 2015; Passolunghi, 2011; Wu, Willcutt, Escovar, & Menon, 2014). However, these studies did not report the prevalence of comorbid developmental dyscalculia and math anxiety or correlation between math anxiety and mathematics performance – as they focused on disentangling specific cognitive profiles of children with math anxiety vs mathematics difficulties or developmental dyscalculia.In particular, several studies focused on working memory profiles of children with math anxiety and developmental dyscalculia (e.g., (Mammarella, Hill, Devine, Caviola, & Szűcs, 2015; Passolunghi, Caviola, De Agostini, Perin, & Mammarella, 2016); or their inhibitory processes (Mammarella, Caviola, Giofrè, & Borella, 2018). For example, Mammarella, et al.

(2015) found that children with high math anxiety and developmental dyscalculia were impaired in working memory tasks in a different way: children with high math anxiety scored loweron a verbal working memory task, while children with developmental dyscalculia scored loweron a visuospatial working memory task. The impairment in verbal working memory in the group of children with high math anxiety is consistent with the hypothesis of Ashcraft andcolleagues (Ashcraft & Kirk, 2001; Ashcraft & Faust, 1994; Hopko, Ashcraft, Gute, Ruggiero, & Lewis, 1998),who suggested that intrusivethoughts can interferewith the ability to perform mathematics tasksby usurping working memory resources of individuals with high math anxiety. Passolunghi, et al. (2016) also found that children with high math anxiety made more intrusion errors than controls in a verbal working memory task, meaning that they were not able to properly inhibit irrelevant information while performing a verbal working memory task. Similarly, consistently with Mammarella et al. (2015), previous studies also indicated that children with developmental dyscalculia were more impaired in visuospatial than in verbal working memory tasks (e.g., Passolunghi & Mammarella, 2010; Szűcs, Devine, Soltesz, Nobes, & Gabriel, 2013; van der Sluis, van der Leij, & de Jong, 2005). As for inhibitory processes, Mammarella and colleagues (2018), compared 8-10 year old children with math anxiety, with or without developmental dyscalculia. The resultsshowed that children with math anxiety without developmental dyscalculia had more difficulty in resistingto proactive interference (i.e., ability to ignore information that are no longer relevant for the execution of a particular task). This result is consistent withthe attentional controltheory (Eysenck et al., 2007), which states that anxietyimpairs processing efficiency because it reducesattentional control.

Overall, these results indicate that math anxiety and developmental dyscalculiamay largely stem from different factors. This, in turn means, thatsuccessful intervention methods should treat differently emotional and cognitive factors (e.g., Caviola, Gerotto, & Mammarella, 2016; Ramirez & Beilock, 2011)that both lead to poor mathematics performance, but for different reasons.

Genetic factorsunderlyingMathematics anxiety

The aetiology of math anxiety can be examined not only at the phenotypic level, such as examining causal links between math anxiety and mathematics performance, but also at the level of genetic and environmental factors. In recent years, a number of studies explored genetic and environmental aetiology ofmathematical abilities and difficulties, and more recently – of math anxiety. Genetic studies can be broadly split intoquantitativegenetic methodologies (e.g., twin and adoption studies) and molecular genetic research. Quantitative genetic research allows for the exploration of the origins of individual differences in specific traits as well as of the co-variation between multiple traits; molecular genetic studies aim toidentify the specific genes related to the specific traits(e.g., Kovas, Malykh, & Gaysina, 2016). Most of the quantitativegenetics studies used the twin method to estimate genetic and environmental influences on individual differences in observed variables (Plomin, DeFries, & McClearn, 2008). Twin method compares phenotypic (observed) similarity between monozygotic twins (who are 100% identical in their DNA) and dizygotic twins (who are 50% genetically similar for those parts of DNA that differ in humans). Heritability is defined as theproportion of individual differences in an observed trait explained bygenetic variation, which can be due to additive or non-additiveeffects of genes. Additive genetic factors are the sum of the effectsof all alleles at all loci contributing to the variation in a trait or to the co-variation between traits. Shared environmental effects contribute tothe similarity of twins growing up in the same family; whereas non-sharedenvironmental effects contribute to differences infamily members and also include measurement error (Kovas et al. 2016).

The role of genetics factors in mathematical ability has been explored in a number of studies, both using the twin method (Kovas et al., 2013; Petrill, Kovas, Hart, Thompson, & Plomin, 2009; Rimfeld, Ayorech, Dale, Kovas, & Plomin, 2016), andmolecular association studies (Davis et al., 2014; Sophia J. Docherty, Kovas, & Plomin, 2011). Kovas, Petrill, and Plomin, (2007)revealed that for different mathematics domains the heritability estimates were moderate and similar across different domains (i.e., ranging from .30 to .45 for mathematical application, understanding of numbers, computation, etc.). Kovas, et al. (2013) analysed literacy, numeracy and fluid intelligence (*g*) in children at ages 7, 9, ad 12. They found that about 65% of the differencesamong children in their literacy and numeracy in theearly school years could be explained by genetic differences,and that the heritability of *g*was significantly lower than that of literacy and numeracy in primary school. According to the authors, heritability of literacy and numeracy could beviewed as an index of educational equality – the more equal/standardised environments are, the more differences in educational outcomes are explained by genetic differences. In fact, in younger students the effects of family environments on *g*were notmitigated by education. In contrast, in older students, the shared environmental influence on *g* declined andwas no longer significantly different from that on literacy and numeracy.

Regarding learning disabilities, studies revealed that monozygotic anddizygotic twins of individuals with developmental dyscalculia were twelve andeight times more likely to have the same disorder, respectively (Alarcón, DeFries, Light, & Pennington, 1997)and more than 50% of siblings of individuals with developmental dyscalculia also had the same disorder(Shalev et al., 2001). Plomin and Kovas (2005) in a review of the literature, suggested that most genes associated with specific learning disabilities, such as developmental dyslexia and dyscalculia, are generalistsin their effects within and betweenlearning disabilities and abilities. For example, genes that affect specific learning disabilitiesare largely the same genesresponsible for normal variation in learning abilities. In addition, genes that affect a specific learning ability and disabilityare alsolikely to affect other learning abilities and disabilities.Moreover, research has suggested that mathematics ability is thought to be influenced by many genesthat have small effects across the entire spectrum of ability(Docherty et al., 2010).

Very few studies to date have investigated the role of genetics factors on math anxiety.Wang et al. (2014)carried out one of the first studies, applying the twin method,which investigated the genetic contributions to math anxiety and to its association with general anxiety and maths performance, in a sample of 51412-year-old children (216 monozygotic, and 298 dizygotictwins).The results revealed that genetic factors accounted for around 40% of the variation in math anxiety, with the remaining variance accounted for by child-specific (non-shared) environmental factors.Multivariate behavioural genetic models explored the aetiology of the overlap between generalanxiety, maths problem solving, and math anxiety.The results showed that 9% of the total variance in math anxiety was associated with genetic influences in commonwith general anxiety and 4% of the total variance wasassociated with non-shared environmental influencesin common with general anxiety. An additional 12% of thetotal variance in math anxiety was associated with geneticinfluences related to maths problem solving. No gender differences were found in the aetiology of anxiety. The authors concluded that although the origins of math anxiety partially overlap with general anxiety and maths performance, the causes of individual differences in these three traits are mostlyindependent (Wang, et al., 2014).In a further study, Malanchini et al. (2017)analysed different forms of anxiety: general, spatial and mathematics anxiety, with the aim to disentangle the origins of their association.Data on general, mathematics and spatial anxiety were collected in alarge sample of more than 1400 twin pairs,assessedonline. The results revealed that all forms of anxiety were moderately heritable (from 30% to 41%). The genetic and environmental architecture of different forms of anxiety was similar for males and females, suggestingthat the same factors are implicated in the aetiology of individual differences in anxiety in boys and girls. Finally, the results indicated a large degree of specificity in the aetiologyof different forms of anxiety, suggesting the importance of studying and potentially treating anxiety forms separately.

Overall, these findings suggest the importance of both genetic and environmental (e.g. socio-cultural and demographic) factors in people's susceptibility to math anxiety.The literature investigating the social and other environmental aspects of math anxiety's aetiology focused on individuals' experiences inside the classroom and home experience related to maths, such as teachers' mind-sets and their maths-related teaching practices(Bursal & Paznokas, 2006; Gresham, 2008; Swars, Daane, & Giesen, 2006); parental involvement in maths education, parental expectations and parents math anxiety experiences(Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015).These studies are described to more extent and detail in the Chapter 11. Future quantitative genetic research is needed to explore genetic and environmental aetiology of covariation between math anxiety and maths performance. In addition, molecular genetic research is needed to identify specific genetic markers involved in the aetiology of math anxiety and its links to maths performance.

Overall conclusions and future directions

The studies reviewed in this chapter suggest the complexity of the phenomenon of math anxiety. Although a moderate negative correlation exists between math anxiety and mathematics performance, the presence of the causal association and direction its effects is still not completely clear. Knowing thedirectionofthemath anxiety -mathsperformancelink can have implicationsforeducationandfor psychology research(Carey et al., 2016). Research has begun to clarifythe differences in cognitive profiles and other characteristics, between students who struggle with mathematics because of math anxiety and students who struggle with maths because of a specific learning disorder, such as developmental dyscalculia(Lai et al., 2015; Mammarella et al., 2015; Mammarella et al., 2018; Passolunghi et al., 2016; Passolunghi, 2011). Additionally, recent research suggests that developmental dyscalculia and math anxiety largely dissociate(Devine et al., 2018).

As for gender differences in math anxiety, previous findings suggested that gender differences maypartly related to gender stereotypes about maths (Appel et al., 2011; Flore & Wicherts, 2015), home environment (Maloney, et al. 2015) and attitudes and beliefs of teachers (Bursal & Paznokas, 2006; Gresham, 2008; Swars et al., 2006). From an interactionist point of view, anxiety is not only the result of an individual predisposition to evaluate an event as threating but also a result of situations demands, people interactions and expectations (e.g., Löwe et al., 2008). Interestingly, genetic studies did not find any gender differences in the aetiology of math anxiety betweenmales and females. In terms of the aetiology of individual differences in math anxiety, genetically informative research suggests high degree of specificity: largely non-overlapping genetic factors contribute to different forms of anxiety (general anxiety, spatial anxiety and math anxiety) and to maths performance (Malanchini et al., 2017; Wang et al., 2014).Further studies should not only consider other influential factors of the direction of math anxiety -maths performance (such as environmental variables and multiple sources reports) but also examinein more depth the cognitive profiles of children withmath anxiety or developmental dyscalculia.

The complexity of the relationship between mathematics difficulties and MA leave several open questions for future studies. For example, the factorsthat moderate the development, growth, and impact of math anxiety should be further explored. The literature has shown that moderatelevels of anxiety help focus attention and enhanceworking memory, whereas extremely high or low levelsof anxiety are associated with insufficient cognitiveresources allocated to the tasks (Arnsten, 2009; Diamond, Barnett, Thomas, & Munro, 2007). Wang et al.(2015)revealed that the facilitating and debilitating effects of math anxiety onmaths performance vary not only across different levels ofmath anxiety, but also as a function of how motivatedchildren are to perform well. Interestingly, Wang et al. (2015) observed the classical inverted-U relation between MA and maths performance only in students showing a high intrinsic motivation, while students with low motivation revealed a negative linear relation between math anxiety and mathematics performance.In another study, Mammarella and colleagues (Mammarella, Donolato, Caviola, & Giofrè, 2018)highlighted the importance of consideringself-concept and resilience in relation to different levels of anxiety risk profiles. Hence, further studies should investigate more in depth individual characteristics that could support and promote academic success and well-being in school-age children and that could prevent the onset or impact of math anxiety.

Another key point for further research is to find effective interventions to reduce the negative impact ofmath anxiety on mathematics achievement. Research suggests that cognitive-behavioural therapy treatment protocols can be effective in reducing anxiety symptoms in school children (Fisak, Richard, & Mann, 2011; Neil & Christensen, 2009). For example, the FRIENDS for life program(Barrett & Pahl, 2006)involves teachers as facilitators to run group sessions as a routine component of the class activity (Lowry-Webster, Barrett, & Dadds, 2001), showing good effectiveness in randomized controlled trials (Fisak et al., 2011; Stallard et al., 2014). As for specific interventions on math anxiety, Supekar, Iuculano, Chen, and Menon, (2015)demonstrated that an intensive eight-week, one-on-one cognitive tutoring program reduces math anxiety in children and improves maths skills through desensitization. In another research, Park, Ramirez, and Beilock, (2014)employed an expressive writingtechnique aimed at reducing the number of intrusivethoughts of individuals with high math anxiety in order to improve their maths performance.Further studies are needed to replicate and extend these promising studies forthe treatment of math anxiety.

In our view, distinguishing students who failed in mathematics for different reasons (high math anxiety vs. developmental dyscalculia) is crucial, in order to give them individualized and specific strategies to cope with math anxiety. Again, individual protective factors such as intrinsic motivation and resilience, and contextual information, such as home environment and interactions with teachers, should be considered as mediator factors.To conclude, to better understand the relation between math anxiety and maths performance not only the potentially complex interplay between emotionand cognition, but also the influence of genetics and contextual factorsshould be fully considered.

References

Ahmed, W. (2018). Developmental trajectories of math anxiety during adolescence: Associations with STEM career choice. *Journal of Adolescence*, *67*, 158–166. https://doi.org/10.1016/J.ADOLESCENCE.2018.06.010

Alarcón, M., DeFries, J. C., Light, J. G., & Pennington, B. F. (1997). A Twin Study of Mathematics Disability. *Journal of Learning Disabilities*, *30*(6), 617–623. https://doi.org/10.1177/002221949703000605

Appel, M., Kronberger, N., & Aronson, J. (2011). Stereotype threat impairs ability building: Effects on test preparation among women in science and technology. *European Journal of Social Psychology*, *41*(7), 904–913. https://doi.org/10.1002/ejsp.835

Arnsten, A. F. T. (2009). Stress signalling pathways that impair prefrontal cortex structure and function. *Nature Reviews Neuroscience*, *10*(6), 410–422. https://doi.org/10.1038/nrn2648

Ashcraft, M. H. (2002). Math Anxiety and Its Cognitive Consequences. *American Psychology Society*, *11*(5), 181–185.

Ashcraft, M. H., & Faust, M. W. (1994). Mathematics anxiety and mental arithmetic performance: An exploratory investigation. *Cognition & Emotion*, *8*(2), 97–125. https://doi.org/10.1080/02699939408408931

Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology. General*, *130*(2), 224–237. https://doi.org/10.1037/0096-3445.130.2.224

Ashcraft, M. H., Krause, J. A., & Hopko, D. R. (2007). Is math anxiety a mathematical learning disability? In D. B. Berch & M. M. M. Mazzocco (Eds.), Why is math so hard for some children? The nature and origins of mathematical learning difficulties and disabilities (pp. 329-348). Baltimore, MD, US: Paul H Brookes Publishing.

Ashcraft, M. H., & Moore, A. M. (2009). Mathematics Anxiety and the Affective Drop in Performance. *Journal of Psychoeducational Assessment*, *27*(3), 197–205. https://doi.org/10.1177/0734282908330580

Ashcraft, M. H., & Ridley, K. S. (2005). Math anxiety and its cognitive consequences: A tutorial review. In J. I. D. Campbell (Ed.), Handbook of mathematical cognition (pp. 315-327). New York, NY, US: Psychology Press.

Beasley, T. M., Long, J. D., & Natali, M. (2001). A confirmatory factor analysis of the mathematics anxiety scale for children. Measurement and Evaluation in Counseling and Development, 34(1), 14

Barrett, P. M., & Pahl, K. M. (2006). School-Based Intervention: Examining a Universal Approach to Anxiety Management. *Australian Journal of Guidance and Counselling*, *16*(01), 55–75. https://doi.org/10.1375/ajgc.16.1.55

Beilock, S. L., & Maloney, E. A. (2015). Math Anxiety. *Policy Insights from the Behavioral and Brain Sciences*, *2*(1), 4–12. https://doi.org/10.1177/2372732215601438

Birgin, O., Baloğlu, M., Çatlıoğlu, H., & Gürbüz, R. (2010). *An investigation of mathematics anxiety among sixth through eighth grade students in Turkey*. *Learning and Individual Differences* (Vol. 20). https://doi.org/10.1016/j.lindif.2010.04.006

Bursal, M., & Paznokas, L. (2006). Mathematics Anxiety and Preservice Elementary Teachers' Confidence to Teach Mathematics and Science. *School Science and Mathematics*, *106*(4), 173–180. https://doi.org/10.1111/j.1949-8594.2006.tb18073.x

Carey, E., Hill, F., Devine, A., & Szücs, D. (2016). The chicken or the egg? The direction of the relationship between mathematics anxiety and mathematics performance. *Frontiers in Psychology*, *6*(JAN), 1–6. https://doi.org/10.3389/fpsyg.2015.01987

Caviola, S., Gerotto, G., & Mammarella, I. C. (2016). Computer-based training for improving mental calculation in third- and fifth-graders. *Acta Psychologica*, *171*. https://doi.org/10.1016/j.actpsy.2016.10.005

Ching, B. H.-H. (2017). Mathematics anxiety and working memory: Longitudinal associations with mathematical performance in Chinese children. *Contemporary Educational Psychology*, *51*, 99–113. https://doi.org/10.1016/J.CEDPSYCH.2017.06.006

Chiu, L. H., & Henry, L. L. (1990). Development and validation of the Mathematics Anxiety Scale for Children. Measurement and evaluation in counseling and development.

Cvencek, D., Meltzoff, A. N., & Kapur, M. (2014). Cognitive consistency and math–gender stereotypes in Singaporean children. *Journal of Experimental Child Psychology*, *117*, 73–91. https://doi.org/10.1016/J.JECP.2013.07.018

Davis, O. S. P., Band, G., Pirinen, M., Haworth, C. M. A., Meaburn, E. L., Kovas, Y., … Spencer, C. C. A. (2014). The correlation between reading and mathematics ability at age twelve has a substantial genetic component. *Nature Communications*, *5*(1), 4204. https://doi.org/10.1038/ncomms5204

Devine, A., Fawcett, K., Szűcs, D., & Dowker, A. (2012). Gender differences in mathematics anxiety and the relation to mathematics performance while controlling for test anxiety. *Behavioral and Brain Functions*, *8*(1), 33. https://doi.org/10.1186/1744-9081-8-33

Devine, A., Hill, F., Carey, E., & Szűcs, D. (2018). Cognitive and emotional math problems largely dissociate: Prevalence of developmental dyscalculia and mathematics anxiety. *Journal of Educational Psychology*, *110*(3), 431–444. https://doi.org/10.1037/edu0000222

Devine, A., Soltész, F., Nobes, A., Goswami, U., & Szűcs, D. (2013). Gender differences in developmental dyscalculia depend on diagnostic criteria. *Learning and Instruction*, *27*, 31–39. https://doi.org/10.1016/j.learninstruc.2013.02.004

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science (New York, N.Y.)*, *318*(5855), 1387–8. https://doi.org/10.1126/science.1151148

Docherty, S. J., Davis, O. S. P., Kovas, Y., Meaburn, E. L., Dale, P. S., Petrill, S. A., … Plomin, R. (2010). A genome-wide association study identifies multiple loci associated with mathematics ability and disability. *Genes, Brain and Behavior*, *9*(2), 234–247. https://doi.org/10.1111/j.1601-183X.2009.00553.x

Docherty, S. J., Kovas, Y., & Plomin, R. (2011). Gene-Environment Interaction in the Etiology of Mathematical Ability Using SNP Sets. *Behavior Genetics*, *41*(1), 141–154. https://doi.org/10.1007/s10519-010-9405-6

Dowker, A., Sarkar, A., & Looi, C. Y. (2016). Mathematics Anxiety: What Have We Learned in 60 Years? *Frontiers in Psychology*, *7*, 508. https://doi.org/10.3389/fpsyg.2016.00508

Else-Quest, N. M., Hyde, J. S., & Linn, M. C. (2010). Cross-national patterns of gender differences in mathematics: a meta-analysis. Psychological bulletin, 136(1), 103.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: attentional control theory. Emotion, 7(2), 336.

Fisak, B. J., Richard, D., & Mann, A. (2011). The Prevention of Child and Adolescent Anxiety: A Meta-analytic Review. *Prevention Science*, *12*(3), 255–268. https://doi.org/10.1007/s11121-011-0210-0

Flore, P. C., & Wicherts, J. M. (2015). Does stereotype threat influence performance of girls in stereotyped domains? A meta-analysis. *Journal of School Psychology*, *53*(1), 25–44. https://doi.org/10.1016/J.JSP.2014.10.002

Foley, A. E., Herts, J. B., Borgonovi, F., Guerriero, S., Levine, S. C., & Beilock, S. L. (2017).

The Math Anxiety-Performance Link. *Current Directions in Psychological Science*, *26*(1), 52–58. https://doi.org/10.1177/0963721416672463

Fredricks, J. A., & Eccles, J. S. (2002). Children's competence and value beliefs from childhood through adolescence: Growth trajectories in two male-sex-typed domains. Developmental psychology, 38(4), 519.

Gresham, G. (2008). Mathematics anxiety and mathematics teacher efficacy in elementary pre-service teachers. *Teaching Education*, *19*(3), 171–184. https://doi.org/10.1080/10476210802250133

Hembree, R. (1988). Correlates, Causes, Effects, and Treatment of Test Anxiety. *Review of Educational Research*, *58*(1), 47–77. https://doi.org/10.3102/00346543058001047

Hembree, R. (1990). The Nature , Effects , and Relief of Mathematics Anxiety. *Journal for Research in Mathematics Education*, *21*(1), 33–46. https://doi.org/10.2307/749455

Hill, F., Mammarella, I. C., Devine, A., Caviola, S., Passolunghi, M. C., & Szűcs, D. (2016). Maths anxiety in primary and secondary school students: Gender differences, developmental changes and anxiety specificity. *Learning and Individual Differences*. https://doi.org/10.1016/j.lindif.2016.02.006

Ho, H.-Z., Senturk, D., Lam, A. G., Zimmer, J. M., Hong, S., Okamoto, Y., … Wang, C.-P. (2000). The Affective and Cognitive Dimensions of Math Anxiety: A Cross-National Study. *Journal for Research in Mathematics Education*, *31*(3), 362. https://doi.org/10.2307/749811

Hopko, D. R., Ashcraft, M. H., Gute, J., Ruggiero, K. J., & Lewis, C. (1998). Mathematics Anxiety and Working Memory: Support for the Existence of a Deficient Inhibition Mechanism. *Journal of Anxiety Disorders*, *12*(4), 343–355. https://doi.org/10.1016/S0887-6185(98)00019-X

Hopko, D. R., McNeil, D. W., Gleason, P. J., & Rabalais, A. E. (2002). The Emotional

Stroop Paradigm: Performance as a Function of Stimulus Properties and Self-Reported Mathematics Anxiety. *Cognitive Therapy and Research*, *26*(2), 157–166. https://doi.org/10.1023/A:1014578218041

Karimi, A., & Venkatesan, S. (2009). Mathematics Anxiety, Mathematics Performance and Academic Hardiness in High School Students. *International Journal of Educational Sciences*, *1*(1), 33–37. https://doi.org/10.1080/09751122.2009.11889973

Koumoula, A., Tsironi, V., Stamouli, V., Bardani, I., Siapati, S., Graham, A., … von Aster, M. (2004). An Epidemiological Study of Number Processing and Mental Calculation in Greek Schoolchildren. *Journal of Learning Disabilities*, *37*(5), 377–388. https://doi.org/10.1177/00222194040370050201

Kovas, Y., Malykh, S., & Gaysina, D. (Eds.). (2016). Behavioural genetics for education. Springer.

Kovas, Y., Petrill, S. A., & Plomin, R. (2007). The origins of diverse domains of mathematics: Generalist genes but specialist environments. *Journal of Educational Psychology*, *99*(1), 128–139. https://doi.org/10.1037/0022-0663.99.1.128

Kovas, Y., Voronin, I., Kaydalov, A., Malykh, S. B., Dale, P. S., & Plomin, R. (2013). Literacy and Numeracy Are More Heritable Than Intelligence in Primary School. *Psychological Science*, *24*(10), 2048–2056. https://doi.org/10.1177/0956797613486982

Kucian, K., Zuber, I., Kohn, J., Poltz, N., Wyschkon, A., Esser, G., & von Aster, M. (2018). Relation Between Mathematical Performance, Math Anxiety, and Affective Priming in Children With and Without Developmental Dyscalculia. *Frontiers in Psychology*, *9*, 263. https://doi.org/10.3389/fpsyg.2018.00263

Lai, Y., Zhu, X., Chen, Y., & Li, Y. (2015). Effects of Mathematics Anxiety and Mathematical Metacognition on Word Problem Solving in Children with and without Mathematical Learning Difficulties. *PLOS ONE*, *10*(6), e0130570.

https://doi.org/10.1371/journal.pone.0130570

Lee, J. (2009). Universals and specifics of math self-concept, math self-efficacy, and math anxiety across 41 PISA 2003 participating countries. *Learning and Individual Differences*, *19*(3), 355–365. https://doi.org/10.1016/J.LINDIF.2008.10.009

Lewis, C., Hitch, G., & Walker, P. (1994). The prevalence of specific arithmetic difficulties and specific reading difficulties in 9-to 10-year-old boys and girls. *Journal of Child Psychology And*. Retrieved from http://onlinelibrary.wiley.com/doi/10.1111/j.1469-7610.1994.tb01162.x/full

LeFevre, J. A., Kulak, A. G., & Heymans, S. L. (1992). Factors influencing the selection of university majors varying in mathematical content. *Canadian Journal of Behavioural Science/Revue canadienne des sciences du comportement, 24*(3), 276.

Löwe, B., Spitzer, R. L., Williams, J. B. W., Mussell, M., Schellberg, D., & Kroenke, K. (2008). Depression, anxiety and somatization in primary care: syndrome overlap and functional impairment. *General Hospital Psychiatry*, *30*(3), 191–199. https://doi.org/10.1016/J.GENHOSPPSYCH.2008.01.001

Lowry-Webster, H. M., Barrett, P. M., & Dadds, M. R. (2001). A Universal Prevention Trial of Anxiety and Depressive Symptomatology in Childhood: Preliminary Data from an Australian Study. *Behaviour Change*, *18*(01), 36–50. https://doi.org/10.1375/bech.18.1.36

Ma, X. (1999). A Meta-Analysis of the Relationship between Anxiety toward Mathematics and Achievement in Mathematics. *Journal for Research in Mathematics Education*, *30*(5), 520–540. https://doi.org/10.2307/749772

Malanchini, M., Rimfeld, K., Shakeshaft, N. G., Rodic, M., Schofield, K., Selzam, S., … Kovas, Y. (2017). The genetic and environmental aetiology of spatial, mathematics and general anxiety. *Scientific Reports*, *7*(1), 42218. https://doi.org/10.1038/srep42218

Maloney, E. A. (2016). Math anxiety: Causes, consequences, and remedia- tion. In K. R. Wentzel & D. B. Miele (Eds.), *Handbook of Motivation at School* (2nd ed., 408–423). New York, NY: Routledge.

Maloney, E. A., Ramirez, G., Gunderson, E. A., Levine, S. C., & Beilock, S. L. (2015). Intergenerational Effects of Parents' Math Anxiety on Children's Math Achievement and Anxiety. *Psychological Science*, *26*(9), 1480–1488. https://doi.org/10.1177/0956797615592630

Mammarella, I. C., Caviola, S., Giofrè, D., & Borella, E. (2018). Separating math from anxiety: The role of inhibitory mechanisms. *Applied Neuropsychology: Child*, *7*(4), 342–353. https://doi.org/10.1080/21622965.2017.1341836

Mammarella, I. C., Donolato, E., Caviola, S., & Giofrè, D. (2018). Anxiety profiles and protective factors: A latent profile analysis in children. *Personality and Individual Differences*, *124*. https://doi.org/10.1016/j.paid.2017.12.017

Mammarella, I. C., Hill, F., Devine, A., Caviola, S., & Szűcs, D. (2015). Math anxiety and developmental dyscalculia: A study on working memory processes. *Journal of Clinical and Experimental Neuropsychology*, *37*(8), 878–887. https://doi.org/10.1080/13803395.2015.1066759

Marsh, H. W., & Yeung, A. S. (1998). Longitudinal Structural Equation Models of Academic Self-Concept and Achievement: Gender Differences in the Development of Math and English Constructs. *American Educational Research Journal*, *35*(4), 705–738. https://doi.org/10.3102/00028312035004705

Moore, A. M., Rudig, N. O., & Ashcraft, M. H. (2014). Affect, Motivation, Working Memory, and Mathematics, 1(September 2016), 1–28. https://doi.org/10.1093/oxfordhb/9780199642342.013.004

Neil, A. L., & Christensen, H. (2009). Efficacy and effectiveness of school-based prevention and early intervention programs for anxiety. *Clinical Psychology Review*, *29*(3), 208–215. https://doi.org/10.1016/j.cpr.2009.01.002

Newstead, K. (1998). Aspects of Children's Mathematics Anxiety. *Educational Studies in Mathematics*, *36*(1), 53–71. https://doi.org/10.1023/A:1003177809664

Organization for Economic Cooperation and Development (2013). PISA 2012 assessmentand analytical framework: Mathematics, reading, science, problem solving and financialliteracy. OECD Publishing.

Organization for Economic Cooperation and Development (2016). PISA 2015 results infocus. OECD Publishing.

Pajares, F. (2005). Gender differences in mathematics self-efficacy beliefs. Gender differences in mathematics: An integrative psychological approach, 294-315.

Park, D., Ramirez, G., & Beilock, S. L. (2014). The Role of Expressive Writing in Math Anxiety. https://doi.org/10.1037/xap0000013

Passolunghi, M. C. (2011). Cognitive and Emotional Factors in Children with Mathematical Learning Disabilities. *International Journal of Disability, Development and Education*, *58*(1), 61–73. https://doi.org/10.1080/1034912X.2011.547351

Passolunghi, M. C., Caviola, S., De Agostini, R., Perin, C., & Mammarella, I. C. (2016). Mathematics anxiety, working memory, and mathematics performance in secondary-school children. *Frontiers in Psychology*, *7*(FEB), 1–8. https://doi.org/10.3389/fpsyg.2016.00042

Passolunghi, M. C., & Mammarella, I. C. (2010). Spatial and visual working memory ability in children with difficulties in arithmetic word problem solving. *European Journal of Cognitive Psychology*, *22*(6), 944–963. https://doi.org/10.1080/09541440903091127

Petrill, S. A., Kovas, Y., Hart, S. A., Thompson, L. A., & Plomin, R. (2009). The Genetic and Environmental Etiology of High Math Performance in 10-Year-Old Twins. *Behavior*

Genetics, *39*(4), 371–379. https://doi.org/10.1007/s10519-009-9258-z

Ramirez, G., & Beilock, S. L. (2011). Writing about testing worries boosts exam performance in the classroom. *Science (New York, N.Y.)*, *331*(6014), 211–213. https://doi.org/10.1126/science.1199427

Richardson, F. C., & Suinn, R. M. (1972). The Mathematics Anxiety Rating Scale: Psychometric data. *Journal of Counseling Psychology*, *19*(6), 551–554. https://doi.org/10.1037/h0033456

Rimfeld, K., Ayorech, Z., Dale, P. S., Kovas, Y., & Plomin, R. (2016). Genetics affects choice of academic subjects as well as achievement. *Scientific Reports*, *6*(1), 26373. https://doi.org/10.1038/srep26373

Shalev, R. S., & Gross-Tsur, V. (2001). Developmental dyscalculia. *Pediatric Neurology*, *24*(5), 337–342. https://doi.org/10.1016/S0887-8994(00)00258-7

Shalev, R. S., Manor, O., Kerem, B., Ayali, M., Badichi, N., Friedlander, Y., & Gross-Tsur, V. (2001). Developmental Dyscalculia Is a Familial Learning Disability. *Journal of Learning Disabilities*, *34*(1), 59–65. https://doi.org/10.1177/002221940103400105

Stallard, P., Skryabina, E., Taylor, G., Phillips, R., Daniels, H., Anderson, R., & Simpson, N. (2014). Classroom-based cognitive behaviour therapy (FRIENDS): a cluster randomised controlled trial to Prevent Anxiety in Children through Education in Schools (PACES). *The Lancet Psychiatry*, *1*(3), 185–192. https://doi.org/10.1016/S2215-0366(14)70244-5

Supekar, K., Iuculano, T., Chen, L., & Menon, V. (2015). Remediation of Childhood Math Anxiety and Associated Neural Circuits through Cognitive Tutoring. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *35*(36), 12574–83. https://doi.org/10.1523/JNEUROSCI.0786-15.2015

Swars, S. L., Daane, C. J., & Giesen, J. (2006). Mathematics Anxiety and Mathematics Teacher Efficacy: What is the Relationship in Elementary Preservice Teachers? *School*

Science and Mathematics, *106*(7), 306–315. https://doi.org/10.1111/j.1949-8594.2006.tb17921.x

Szűcs, D., Devine, A., Soltesz, F., Nobes, A., & Gabriel, F. (2013). Developmental dyscalculia is related to visuo-spatial memory and inhibition impairment. *Cortex*, *49*(10), 2674–2688. https://doi.org/10.1016/j.cortex.2013.06.007

van der Sluis, S., van der Leij, A., & de Jong, P. F. (2005). Working Memory in Dutch Children with Reading- and Arithmetic-Related LD. *Journal of Learning Disabilities*, *38*(3), 207–221. https://doi.org/10.1177/00222194050380030301

Wang, Z., Hart, S. A., Kovas, Y., Lukowski, S., Soden, B., Thompson, L. A., … Petrill, S. A. (2014). Who is afraid of math? Two sources of genetic variance for mathematical anxiety. *Journal of Child Psychology and Psychiatry*, *55*(9), 1056–1064. https://doi.org/10.1111/jcpp.12224

Wang, Z., Lukowski, S. L., Hart, S. A., Lyons, I. M., Thompson, L. A., Kovas, Y., … Petrill, S. A. (2015). Is Math Anxiety Always Bad for Math Learning? The Role of Math Motivation. *Psychological Science*, *26*(12), 1863–1876. https://doi.org/10.1177/0956797615602471

Wu, S. S., Willcutt, E. G., Escovar, E., & Menon, V. (2014). Mathematics Achievement and Anxiety and Their Relation to Internalizing and Externalizing Behaviors. *Journal of Learning Disabilities*, *47*(6), 503–514. https://doi.org/10.1177/0022219412473154