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

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Chapter 8

Math Anxiety in children with and without mathematical

difficulties:

The role of gender and genetic factors

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Mathematics anxiety is generally defined as feeling tense, fearful and apprehensive about mathematics (Richardson & Suinn, 1972). It is 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 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 anxiety seems 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 anxiety also affects society. For example, in the USA math anxiety may 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 anxiety has become a subject of increasing interest in educational, rather than only clinical settings. Many factors are involved in the links between math anxiety and 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 of math anxiety, focusing on gender differences, distinction between mathematics difficulties related to math anxiety vs those related to specific mathematics impairments, and the role of genetic factors.

Gender differences in Math anxiety and Mathematics performance

Math anxiety has 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-old 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 students reported 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 anxiety has 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 anxiety than 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 anxiety was 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 anxiety had poorer

performance in mathematics than students who reported lower levels of math anxiety (Foley et al., 2017).

Several conclusions about math anxiety can 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 anxiety has been observed in both western and eastern countries (Ching, 2017; Ho et al., 2000; Lee, 2009). Second, math anxiety is robustly negatively correlated with mathematics performance, in both boys and girls (roughly $r = -.30$; Hembree, 1990; Ma, 1999). Third, the negative relation between math anxiety and mathematics 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 anxiety than 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 anxiety seem 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 anxiety in 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).

Although several cross-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 objective measure of mathematics performance (i.e., Ahmed, 2018). Different hypotheses have been proposed. A possible 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 proportion of students have cognitive and/or emotional difficulties in dealing with mathematics (Hopko, McNeil, Gleason, & Rabalais, 2002). There are two major reasons for why a student fails in mathematics: the presence of a specific learning disorder in mathematics (i.e., developmental dyscalculia), or the presence of emotional issues that affect mathematics performance, 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 and ruminations, often about the consequences of failure in maths tasks (Ashcraft & Kirk, 2001). Thus, cognitive resources, such as working memory, that are needed for success in 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 poor mathematics performance. According to this account, a student's reduced competency in maths leads to weaker learning and performance, which then contribute to the development of math anxiety (Maloney, 2016). Math anxiety is thus an outcome of poor mathematics skills. Another proposed framework within this account, suggests that students who have reduced maths abilities avoid taking maths classes and learning mathematics in general. This avoidance can contribute to successive failures and lead to the development of math 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 children in UK. The results demonstrated that developmental dyscalculia and math anxiety largely dissociate, calling into question the idea that low mathematics performance is the primary cause of math anxiety. In particular, Devine and colleagues (2018) showed that using a threshold of high math anxiety at or above the 90th

percentile, 10% of students with typical mathematics performance had high math anxiety; and 22% percent of students 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 subgroup with co-morbid developmental dyscalculia and math anxiety. which, again, is in line with findings reporting 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 lower on a verbal working memory task, while children with developmental dyscalculia scored lower on 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 and colleagues (Ashcraft & Kirk, 2001; Ashcraft & Faust, 1994; Hopko, Ashcraft, Gute, Ruggiero, & Lewis, 1998), who suggested that intrusive thoughts can interfere with the ability to perform mathematics tasks by 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 results showed that children with math anxiety without developmental dyscalculia had more difficulty in resisting to proactive interference (i.e., ability to ignore information that are no longer relevant for the execution of a particular task). This result is consistent with the attentional control theory (Eysenck et al., 2007), which states that anxiety impairs processing efficiency because it reduces attentional control.

Overall, these results indicate that math anxiety and developmental dyscalculia may largely stem from different factors. This, in turn means, that successful 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 factors underlying Mathematics 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 of mathematical abilities and difficulties, and more recently – of math anxiety. Genetic studies can be broadly split into quantitative genetic 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 to identify the specific genes related to the specific traits (e.g., Kovas, Malykh, & Gaysina, 2016). Most of the quantitative genetics 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 the proportion of individual differences in an observed trait explained by genetic variation, which can be due to additive or non-additive effects of genes. Additive genetic factors are the sum of the effects of all alleles at all loci contributing to the variation in a trait or to the co-variation between traits. Shared environmental effects contribute to the similarity of twins growing up in the same family; whereas non-shared environmental effects contribute to differences in family 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), and molecular 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, and 12. They found that about 65% of the differences among children in their literacy and numeracy in the early 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 be viewed 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 not mitigated by education. In contrast, in older students, the shared environmental influence on g declined and was no longer significantly different from that on literacy and numeracy.

Regarding learning disabilities, studies revealed that monozygotic and dizygotic twins of individuals with developmental dyscalculia were twelve and eight 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 generalists in their effects within and between learning disabilities and abilities. For example, genes that affect specific learning

disabilities are largely the same genes responsible for normal variation in learning abilities. In addition, genes that affect a specific learning ability and disability are also likely to affect other learning abilities and disabilities. Moreover, research has suggested that mathematics ability is thought to be influenced by many genes that 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 dizygotic twins). 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 general anxiety, maths problem solving, and math anxiety. The results showed that 9% of the total variance in math anxiety was associated with genetic influences in common with general anxiety and 4% of the total variance was associated with non-shared environmental influences in common with general anxiety. An additional 12% of the total variance in math anxiety was associated with genetic influences 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 mostly independent (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 a large sample of more than 1400 twin pairs, assessed online. 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, suggesting that 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 aetiology of 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 the direction of the math anxiety -maths performance link can have implications for education and for psychology research (Carey et al., 2016). Research has begun to clarify the 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 may partly be 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 threatening 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 between males 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 examine in more depth the cognitive profiles of children with math anxiety or developmental dyscalculia.

The complexity of the relationship between mathematics difficulties and MA leave several open questions for future studies. For example, the factors that moderate the development, growth, and impact of math anxiety should be further explored. The literature has shown that moderate levels of anxiety help focus attention and enhance working memory, whereas extremely high or low levels of anxiety are associated with insufficient cognitive resources

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 on maths performance vary not only across different levels of math anxiety, but also as a function of how motivated children 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 considering self-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 of math 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 writing technique aimed at reducing the number of intrusive thoughts of individuals with high math anxiety in order to improve their maths

performance. Further studies are needed to replicate and extend these promising studies for the 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 emotion and cognition, but also the influence of genetics and contextual factors should be fully considered.

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