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# Math Anxiety: How close are we to solving the puzzle?

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## ABSTRACT

The main focus of this thesis is to determine to what extent the research on math anxiety has flourished mainly in the light of psychological variables. Considering the history of math anxiety, the thesis attempts to discuss joint research strands in the literature and their departures. Further, to close the gap between math anxiety and math performance research areas, this work highlights the multidimensional nature of math anxiety and its correlates, encompassing crucial empirical studies. A great line of research from developmental studies has shown that math anxiety can develop in early childhood; therefore, it is inevitable to emphasize early intervention for math anxiety. However, the results on the impact and effectiveness of the interventions to reduce math anxiety, particularly among school children, are found to be susceptible to duration and type of intervention used. Moreover, the current thesis suggests focusing on unique factors such as individual differences and mathematics resilience, among others discussed, that might add up to solving the math anxiety puzzle.

KEYWORDS: Math anxiety, Math performance, Intervention, Individual difference, Mathematics resilience

## INTRODUCTION

In 2019, anxiety was found to be one of the most common mental disorders among 301 million people around the world, which includes 58 million children and adolescents (WHO, 2022). In particular, people can also be afflicted by unique or specific forms of test and performance anxiety in educational settings (Sawka-Miller, 2011). Furthermore, the most well-known among these is considered to be math anxiety (Luttenberger et al., 2018). The research on math anxiety as a construct gained importance with the introduction of the concept of number anxiety by Dreger and Aiken in 1957 (Dowker et al., 2016) and has received immense attention, mainly because of the increased focus on math performance globally (OECD, 2013).

According to Richardson and Suinn (1972), math anxiety is a tense feeling of fear and apprehension about mathematics; similarly, Ashcraft and Ridley (2005) define it as negative state related to mathematics and mathematical solutions and fear of possible negative evaluation of performance related to math. Some other definitions provided by Lazarus and Tobias (as cited in Cipora et al., 2022) characterize math anxiety as excessive or irrational fear, panic, and helplessness while performing math-related problems. The former definitions consider math anxiety as a trait or state, while the latter are clinical. Considering different perspectives and definitions of math anxiety might help us understand its theories, with the entire spectrum in the background (Cipora et al., 2022). This thesis is a literature review of possible aspects of math anxiety, mainly inspired by the research work of Prof. Irene Mammarella and Prof. Sara Caviola (evident in the chapters ahead).

Math anxiety is present across several development stages, starting early elementary school and increasing until adulthood (Caviola et al., 2021). Previous research has shown that various age groups are vulnerable to its effects, and until recently, much of the studies focused on college students (Ramirez et al., 2018). However, this thesis will mainly discuss the role of math anxiety among primary and secondary school children of the age group 6 - 18 years. Below are three main points highlighting the importance of addressing math anxiety right from primary school.

a) Firstly, research focused on adults and their qualitative reports indicate that the cause of math anxiety is rooted in earlier math experiences (Jackson & Leffingwell, 1999). Supporting evidence comes from Aarnos and Perkkilä's study (2012), which found that initial signs of math anxiety may emerge as early as six years of age. Others provided reliable evidence on experiencing math anxiety in the primary school years (Ramirez et al., 2013; Ramirez et al., 2016; Thomas & Dowker, 2000).

b) Secondly, focusing on the early years of math anxiety is important because of its long-term damaging effects, such as increased difficulty with greater cognitive demands of math problems, the tendency to develop negative beliefs about their math abilities, which might lead to more math anxiety, and finally, resulting in avoidance (Passolunghi et al., 2016). The latter has a detrimental effect on long-term career choices, such as being less likely to pursue Science, Technology, Engineering, and Mathematics (STEM) careers (Ashcraft & Ridley, 2005; Hembree, 1990). Furthermore, studies that look at math anxiety from a developmental perspective have confirmed a negative correlation between math anxiety and mathematics performance ($r = -0.30$ from Caviola et al. and $r = -0.28$ from Barroso et al.), which might increase across schooling years, mainly when math as a subject becomes cognitively demanding (Barroso et al., 2021; Caviola et al., 2021; Hembree, 1990; Wu et al., 2012).

c) Lastly, in 2012, the Programme for International Student Assessment (PISA) study assessed the competencies of 15-year-old students across the Organization for Economic Co-operation and Development (OECD) countries and reported that one in three students feels anxious when confronted with math problems; 59% of students reported getting worried while in mathematics classes; 33% reported getting very tense while doing mathematics homework; 31% reported getting very nervous doing mathematics problems; 30% reported feeling helpless when doing a mathematics problem; and 61% reported being worried about getting poor grades in mathematics (PISA, OECD, 2015). Though the above statistics might not include all the countries, the effect of math anxiety shown by 65 countries participating in the PISA study cannot be ignored.

The thesis is divided into four chapters. The first chapter provides a brief theoretical background of math anxiety and various approaches and perspectives adapted while understanding math anxiety. Although there is no explicit agreement on dimensions in the literature regarding the multidimensional nature of math anxiety, affective (feelings of nervousness and dread) and cognitive (worry component of anxiety) dimensions will be discussed in this chapter, which are consistently found in the literature. Studies show that math anxiety may be higher in girls than boys; however, at which level of schooling, i.e., primary or secondary, and why it is so is still unclear (Dowker et al., 2016). The last segment in this chapter provides possible explanations from the previous research on the role of stereotypes and gender differences in math anxiety.

Considering the negative association between math anxiety and math performance from previous research (Barroso et al., 2021; Caviola et al., 2021; Hembree, 1990; Ma, 1999) and the relation between math anxiety prevalence and low achievement in math (OECD, 2015), it is vital to consider the etiology of math anxiety. Therefore, the second chapter mainly focuses on the etiology of math anxiety by describing external and internal factors and associated causes. Furthermore, this thesis tries to identify possible protective factors related to math anxiety.

Once a strong base on the theoretical framework of math anxiety is established in the first and second chapters, the third chapter continues to deliver empirical evidence in the literature regarding crucial findings on math anxiety, focusing mainly, but not limited to, the research done by Prof. Irene Mammarella and Prof. Sara Caviola. The third chapter is divided into the following sub-sections:

1) comparative studies highlighting the similarities and differences among children with and without math anxiety and mathematical disability while considering math achievement;

2) significant takeaways from the multidimensional approach studies that analyze children's behavioral, emotional, cognitive, and psychophysiological responses to math anxiety are reported;

3) correlational studies on math anxiety, math performance, the role of working memory, and individual differences; findings from studies on intergenerational effects of adults (parents and teachers) on math anxiety among children, and interventional studies focusing on improving math performance by reducing math anxiety among school children;

4) results from studies on types of anxiety and emerging student profiles;

5) cross-cultural studies;

6) focus on mathematics resilience as a protective factor against math anxiety.

The fourth chapter discusses the concept of mathematics resilience, focusing on psychological characteristics such as anxiety, growth mindset, motivation, and self-efficacy, mainly through the work of Johnston-Wilder and Lee. Lastly, the thesis concludes providing reflections and suggestions, mostly in line with the influential paper by Cipora et al. (2022), along with a few additional contributions. It comprises the evidence gathered through empirical studies by answering possible questions, such as why individual differences have become crucial while planning interventions for math anxiety, mainly in educational settings.

What are the gains and pains of unifying the various approaches discussed in previous chapters on math anxiety? Can mathematics resilience be a potential protective factor for math anxiety? Should educational settings consider the consequences of math anxiety beyond its association with math performance? Would having more longitudinal studies on math anxiety (in addition to the current cross-sectional studies) provide a clear developmental trajectory for math anxiety? Lastly, how close we are to filling the gap in unifying math anxiety research with real-world scenarios (for example, classroom interventions) is addressed.

# CHAPTER 1: THEORETICAL BACKGROUND OF MATH ANXIETY

The literature on math anxiety presents a range of definitions. In the opinion of Cipora et al. (2022), the critical point is to acknowledge the diverse approaches and theoretical foundations behind each definition. This chapter delves into the various perspectives of researchers, ultimately leading to distinct research orientations of math anxiety, which underscores the importance of understanding math anxiety as a psychological construct.

## 1.1 Research Orientations and Psychological Constructs

The primary perspectives used to comprehend math anxiety are personality construct, cognitive construct, sociocultural construct, and neurobiological construct (Ashcraft, 2019, as cited in Cipora et al., 2022). The chapter begins by examining the various approaches and perspectives on math anxiety, the significant theories used in understanding it, and a few supporting studies.

### *1.11 Personality Construct*

According to Ashcraft (2019), Dreger and Aiken's first empirical paper in 1957 led to research on math anxiety as a personality construct. By mainly exploring how math anxiety as a dimension of an individual intersects with other personal characteristics, traits, and factors. Ashcraft describes that on the one side, the research focused on personality characteristics comprising attitudes such as self-confidence in math, enjoyment of math, self-efficacy, and so forth, and on the other side, performance measures such as math achievement under educational outcomes. The most influential work by Hembree (1990) and Ma (1999) (the former is a meta-analysis of 151 studies on the construct of mathematics anxiety, and the latter is a meta-analysis of 26 studies on the relationship between anxiety towards mathematics and achievement in mathematics among elementary and secondary school children) provides insight on how these factors, traits, or characteristics correlate with math anxiety (Ashcraft, 2019). In this sub-section, two crucial aspects of math anxiety are discussed: math anxiety as a separate construct from test and general anxiety and the state-trait discrepancy of math anxiety.

**Math, Test, and General Anxiety.** Assessments are crucial in understanding the correlation or association between math anxiety and other individual factors (Ashcraft, 2019). Cipora et al. (2019) stated that the Math Anxiety Rating Scale (MARS) by Richardson and Suinn (1972), along with its subsequent versions, was found to be highly reliable and most widely used assessment tool (in the form of self-report) to determine math anxiety at the individual level. From Hembree's meta-analysis (1990, as cited in Aschraft, 2019) using MARS, it was identified that the measures of math anxiety correlate more with one another ($r \sim 0.5\text{-}0.8$) than with test anxiety ($r = 0.52$) or general anxiety (r = 0.35). Recently, Dowker et al. (2016, p. 2) asserted that "math anxiety cannot be reduced either to test anxiety or general anxiety." Therefore, it is essential to understand math anxiety separately from general and test anxiety, wherein Živković et al. (2023) referred to general anxiety as individuals' tendency to worry in general and test anxiety as a specific type of anxiety triggered by test or assessment situations.

The results on mean correlations of math anxiety and other anxiety measures (Hembree, 1990) summarize that math anxiety is more closely related to test anxiety (r = 0.52) than general anxiety (r = 0.35). Other measures of math anxiety, such as attitudes concerning math, avoidance behaviors, and math performance, were all negatively correlated (Hembree, 1990). According to Ashcraft (2019), after identifying the close association between math and test anxiety, Hembree considered the *interference model* of test anxiety as a base to develop a theoretical model for math anxiety. Ashcraft (2019) described the interference model, stating that according to this model, test anxiety interferes with recalling previous learning while taking the test, during which the individual's worry results in shifting attention from the test itself. Considering this as a starting point, in Ashcraft's opinion, the research on math anxiety as a personality construct flourished by focusing on the association between math anxiety and personal factors with math achievement (the third chapter will discuss research studies confirming similar associations with math anxiety).

**State-Trait Aspect of Math Anxiety.** In their opinion paper, Cipora et al. (2022) emphasize that when math anxiety is considered as a personality construct, it must be addressed separately as a state-trait case. More recent work by Orbach et al. (2019, as cited in Cipora et al. 2022) suggests this distinction might help deepen the theoretical understanding of math anxiety. To achieve the same, the Orbach et al. (2019) relied on Spielberger's (1972) state-trait anxiety model to distinguish state-math anxiety from trait-math anxiety. According to this model, state-math anxiety is experienced in math-related situations, increasing autonomic nervous system arousal (ANS). Meanwhile, trait-math anxiety, characterized as a personality trait, consists of an acquired disposition that is relatively stable over time, such as a fear of failure in math (Orbach et al., 2019).

In Orbach et al.'s (2019) perspective, research measures change according to the conceptions of math anxiety; that is, operationalizing fear of failure in math would provide a measure of trait-math anxiety, and operationalizing anxiety experienced in situations related to math would give a measure of state-math anxiety. Orbach et al. further emphasized that knowing this distinction is vital because Spielberger (as cited in Orbach et al., 2019, p. 372) "assumed that the frequency and intensity of state anxieties influence the development of personality traits." The study by Caviola et al. (2017, p. 10) reports that "there is some evidence that math anxiety interacts with timed or high-stakes conditions to cause further performance decrement than usual." If this is true, then as Cipora et al. (2022), suggest, planning appropriate interventions to prevent state anxiety (due to timed or high-stakes conditions) from developing might help reduce the adverse effects (decrement in performance and math-anxious personality in the long run) of math anxiety at the individual level. However, Caviola et al. cautioned that currently, no evidence supports any causal relationship between time pressure and inducing math anxiety.

Though the research on math anxiety considering state-trait distinction has gained attention, Orbach et al. (2019) provide two major criticisms. Firstly, they argue that not having universal diagnosis criteria might lead to different ways of operationalizing math anxiety, resulting in inconsistencies among studies related to math anxiety and performance, especially among children. Secondly, in the authors' opinion, self-report does not provide a real-time assessment of anxiety in math situations because it requires ratings given to hypothetical or retrospective questions on anxiety in math-related situations that do not assess state-math anxiety. These issues will be explored further in future chapters, along with relevant research findings.

### *1.12 Cognitive Construct*

The importance of addressing math anxiety through the lens of cognitive construct comes from the 2012 PISA study, where 61% of students expressed worry (cognitive component) about poor math performance (OECD, 2013). Besides, Caviola et al. (2021, p. 364) found that "14% of the variation in math performance was explained by variations in math anxiety" across OECD countries. Therefore, this sub-section addresses math anxiety as a cognitive construct, describing how it develops and impacts performance in math. The theoretical base for math anxiety as a cognitive construct is rooted in the work of Eysenck and Calvo (1992) on the *processing efficiency theory,* the *attentional control theory* by Eysenck et al. (2007), and much recent work by Ramirez et al., (2018) on the *disruption account, reduced competency account,* and *interpretation account* (as cited in Aschraft, 2019).

According to the *processing efficiency theory*, worry comprises an internal process that eventually occupies our consciousness during an anxiety reaction. It was predicted that the resulting preoccupation could impede the working memory system (Eysenck & Calvo, 1992, as cited in Ashcraft, 2019. In a meta-analysis study addressing cognitive aspects in mathematics performance, Caviola et al. (2021) describe how worrying, such as intrusive thoughts of failure (cognitive components of math anxiety), while attempting to solve math problems, are believed to overtax individuals' working memory system, resulting in greater difficulty in solving math-related problems. The authors consider this to be the case mainly because the processes involved in math problems such as "estimation, long-division, problem-solving, and calculations in algebra" were found to depend heavily on the working memory system (p. 238). Indeed, Eysenck (1992, as cited in Ashcraft, 2019) proposed that the demands placed on working memory might impact an anxious individual's performance on cognitive tasks. Later, Ashcraft and Krik (2001, as cited in Ashcraft, 2019) extended processing efficiency theory to math anxiety in a dual-task setting involving addition problems of increasing difficulty, demonstrating that under higher working memory load, people with high math anxiety made more errors compared to people with low math anxiety. Further, this idea was reinforced by Dowker et al. (2016), who indicated a plausible explanation for the decrease in math performance due to math anxiety to be the heavy load on working memory and associated ruminative thoughts.

*Attentional control theory* provides another theoretical base for explaining the negative impact of anxiety on performance (Ashcraft, 2019). The central assumption of this theory is that anxiety shifts attention to threat-related stimuli that are irrelevant to the task, leading to the reduction of cognitive resources necessary for the current task (Caviola et al., 2017; Caviola et al., 2021). The study done by Caviola et al. (2012, as cited in Caviola et al., 2017) on the involvement of working memory in mental addition, reported that there is a drop in performance efficiency while doing math problems related to carrying or borrowing, which may be due to the high demand on working memory, especially when there is also the interference of math anxiety.

According to Ashcraft (2019), the *disruption account* refers to the *w*orry and ruminations about one's math anxiety disrupt working memory, wherein either the former consumes the latter, or one cannot inhibit paying attention to the ruminating thoughts. Ashcraft supposes that the inhibition function (i.e., to withdraw attention from task-irrelevant stimuli) acts as a specific aspect of working memory that might be affected by math anxiety, resulting in a transient disruption of performance (due to interference in working memory). On the other hand, in the reduced competency account, individuals with high math anxiety are considered not to have sufficient math skills as their counterparts (individuals with low math anxiety), which results in global disruption of performance (due to low competence in math) (Ashcraft, 2019).

Ramirez et al., (2018) established a contrasting situation by questioning why poor math abilities or negative experiences lead to math anxiety in some students but not others and why some higher-achieving students in math are also higher in math anxiety than the rest. They proposed an *interpretation account* (similar to Lazarus appraisal theory, 1991) of math anxiety to address these contradictory situations. According to this account, math anxiety depends on how one interprets or appraises previous experiences and outcomes related to math. Ramirez et al. (2018) provide evidence for *the interpretation account* from Meece et al.'s study done in 1990. The study found that the interpretations used by students about their math performance were strong predictors of their math anxiety but not their actual prior achievement in math classes. The authors conclude by arguing how maladaptive interpretations of current and prior math experiences might be critical factors in determining who is prone to develop math anxiety and whose performance in math might suffer as a consequence (Ramirez et al., 2018). Meanwhile, in their study, Mammarella et al. (2023)

reinforce that variations in elicited state-math anxiety are possible based on how individuals interpret their math-related experiences, as further indicated in the third chapter.

### *1.13 Sociocultural Construct*

Math anxiety as a sociocultural construct addresses interpersonal and environmental factors (i.e., social and cultural factors) and their influence on the individual's math anxiety. This sub-section will briefly discuss studies focusing on the influence of parental and teacher expectations and support, parent and teacher attitudes towards maths and their children and students, respectively, and cultural background.

It is evident from the previous sub-sections that the relationship between math anxiety and math performance might differ across individuals according to their personal (trait and state) and cognitive factors such as attentional bias and worries (Ashcraft, 2019). Similarly, the relationship between math anxiety and math performance may differ across countries, regions, or continents. That is, different countries have varying levels of math anxiety, which are found to be negatively associated with math performance. In the 2012 PISA study, countries that performed below the OECD average (i.e., < 400 points) had students reporting high levels of math anxiety along with poor math performance. On the other hand, countries that performed above the OECD average (494 score points) reported low anxiety levels. Interestingly, the study reports that not all countries follow this similar pattern. For example, countries with high performance in mathematics also reported higher levels of math anxiety, including Japan, China, and Korea, to name a few (OECD, 2015). The above arguments hint that the research must also focus on sociocultural aspects of math anxiety to understand such diverse results globally.

While addressing math anxiety as a sociocultural construct, Ashcraft (2019) discusses how teachers' behaviors and attitudes toward math might affect students' attitudes toward math. Specifically, Ashcraft mentions that the teacher's math anxiety directly relates to students' math abilities and achievement beliefs. In one particular study by Beilock et al. (2010, as cited in Herts et al., 2019), it was found that girls exhibited more gender-stereotyped beliefs along with low math achievement compared to boys when their teachers were highly math-anxious. The crucial point made by the authors is that there was no difference in students' attitudes at the beginning of the school year, and all the teachers were female. Research on socioenvironmental factors of math anxiety by Ramirez et al. (2018) suggests that math-anxious parents can impact their children's math anxiety only when parents frequently help their children with math homework. However, the authors identified that when help was not provided, parents' math anxiety was not related to their children's math anxiety. The authors speculate the role of parental beliefs and their experience with math during frequent interaction might have increased math anxiety among their children.

In an investigation study by Lee (2009, as cited in Dowker et al., 2016), children's anxiety levels from high-achieving Asian countries and high-achieving Western European countries were found to be significantly different. It was higher in former countries than in the latter. According to Dowker et al. (2016), possible reasons could be perceived pressure (from parents and teachers) to do well on exams, which is found to be significantly higher in Asian countries, or aspects of educational systems or curricula in general. At the global level, Ashcraft (2019) stated that economically developed and high gender-equal countries have lower anxiety levels than countries that are less developed and low in gender equality. However, Ashcraft pointed out that gender difference in math anxiety was found to be more prominent among developed countries compared to less developed ones as studies related to gender differences and gender stereotypes associated with math anxiety will document in the upcoming chapters.

### *1.14 Neurobiological Construct*

The literature on the biological components of math anxiety alone is very scarce; however, supporting evidence from recent studies on brain mechanisms and regions underlying math anxiety has been helpful in understanding it to the fullest (Ashcraft, 2019). The results of the first empirical research study on the genetic contribution to math anxiety by Wang et al. (as cited in Ramirez et al. 2018, p. 149) showed that "40% of the variation in math anxiety was accounted by genetic factors and the remaining by specific individual environmental factors" in the group of twin siblings (monozygotic & dizygotic of average age of 12.25 years). Wang et al. (2014) consider it to be crucial while planning interventions to explore possible biological routes which might lead to math anxiety and not just limit our focus to the negative experiences that stem from doing math-related activities.

Other studies, such as those discussed by Ashcraft (2019) and Ramirez et al. (2018) provide brain-based evidence for the existence of math anxiety and how it operates. Findings from two of the studies are briefly mentioned below. Young et al. (2012), examined children aged 7 to 9 on addition and subtraction problems. The fMRI findings during the task revealed that math anxiety correlates with increased activity in the amygdala, a brain region linked to fear and negative emotions. Additionally, the researchers discovered that children experiencing high levels of math anxiety exhibited diminished activation in areas previously identified as critical for mathematical and numerical reasoning, specifically the intra-parietal sulcus and angular gyrus (Ashcraft, 2019).

Lyons and Beilock's fMRI study (2012) was conducted among college students with high and low math anxiety. Students were presented with a math task block and a verbal task block, along with a cue that indicated if the next set of trials was math or verbal. They found that in the duration between cue and task completion, students who were high on math anxiety and performing well showed increased activation in the frontoparietal network, which is also involved in controlling negative emotions. On the other hand, students with low math anxiety did not show this increased activity. The authors suggested that the success of students with high math anxiety on the task might be due to using the frontoparietal regions to reappraise their thoughts before the math task (Ramirez et al., 2018).

### 1.2 Math Anxiety as a Multifaceted Phenomenon - Multidimensional Construct

Dowker et al. (2016, p. 2) specify two different dimensions of math anxiety: the *cognitive* dimension, which corresponds to "worry" regarding one's performance and the consequences of failure (intrusive thoughts), and the *affective* dimension, which corresponds to "emotionality that refers to nervousness and tension in testing situations" along with autonomic reactions (negative feelings). The cognitive and affective dimensions were discussed earlier in this chapter. In addition, other types of responses, such as *physiological*, comprising increased arousal and agitation, and *behavioral*, including avoidance behaviors when confronted with math-related situations, are considered to characterize math anxiety as a multidimensional construct (Caviola et al., 2019).

Using the reduced competency account, Ramirez et al., (2018,) suggested that students with low math abilities might avoid taking math classes (a behavioral response to math anxiety) and make no effort to improve their math skills. The authors claim that this avoidance leads to lagging in math understanding, further resulting in math anxiety. The authors strengthen their claim by providing evidence from previous studies that report math-anxious students register for fewer math courses.

The notion of evidence for math anxiety from the physiological dimension comes from Mattarella-Micke et al. (2011, as cited in Ramirez et al., 2018). The authors theorized that a high physiological reaction (sweat or high heartbeat) among students with low math anxiety could be used to interpret the situation as demanding and expect increased performance. Conversely, a high physiological reaction among students with high math anxiety could be interpreted as suffering related to math, leading to worries and inadequate performance. Ramirez et al. (2018) summarized how the data from Mattarella-Micke and colleagues' study indicated that increased levels of cortisol among students with low math anxiety was positively associated with math performance, and the same were found to be negatively associated among students with high math anxiety. However, Dowker et al. (2016) consider there might be modulatory relationships between cortisol levels, math anxiety, and math performance, and the authors clarify that there is no sufficient evidence for cortisol levels to be a reliable indicator of math anxiety. The authors further advocate integrating research findings across behavioral, cognitive, and biological dimensions to understand math anxiety fully.

The various constructs addressed in this chapter indicate that math anxiety is a multifaceted phenomenon. In Ashcraft's (2019, p. 16) words, each approach only adds to the existing knowledge, and they are "all mutually compatible." That is, none of the constructs contradict one another crucially. For example, the fMRI study by Lyons and Beilock (as cited in Ramirez et al., 2018) as evidence for math anxiety under neurobiological construct also confirmed and added to the interpretation account of math anxiety under cognitive construct. Ramirez et al. (2018) further suggested that the process of appraisal before, during, and after the math task might help in explaining the causes of math anxiety and in identifying who is vulnerable to its effects. According to Ramirez et al., math-anxious parents can impact their children's math anxiety only during frequent help with math homework. This can be because children interpret the frequent help from parents as a reminder that they are not good at math. It can also be due to the transmission of parents' attitudes that math is not easy, which might lead children to develop a low perception of their math ability. Therefore, using cognitive and sociocultural constructs of math anxiety in this way, Ramirez et al. (2018) highlighted the role of external influences that shape students' appraisal.

**1.3 Role of Stereotypes and Gender Differences in Understanding Math Anxiety**

Stoet et al. (2016, cited in Ramirez et al., 2018) with 761,655 high school students who participated in PISA, disclosed that female students consistently reported higher math anxiety than male students. The study also discovered that math anxiety and the gender gap widened as a function of the country's economic development. In Ramirez et al.'s view, the literature on the role of gender in math anxiety provides mixed results where some studies indicate women report higher levels of math anxiety than men, and in a few others, no such trend is seen. However, the authors conclude that on a large scale, gender differences are expected while addressing math anxiety. In fact, the meta-analysis study of Hembree in 1990 (as cited in Ashcraft, 2019) found that female students scored 20 points higher on math anxiety than male students consistently at each grade. However, Ashcraft noted that female students frequently rated themselves lower on math performance compared to male students despite no significant gender differences seen in their actual performance (Ashcraft, 2019).

One possible explanation, as articulated by Ashcraft (2019), is that the higher levels of math anxiety among females might be due to the high prevalence of clinical anxiety disorders among females and higher levels of anxiety in general. Since there is a positive correlation between general anxiety and math anxiety ($r = 0.35$ from Hembree, 1990), Ashcraft speculated that the same trend of gender difference might be followed in the case of math anxiety as well. Another speculation by Ashcraft is that females might be able to report more accurately their math anxiety than males, which might explain why the gender difference is evident only in the case of reporting math anxiety and is almost negligible when it comes to actual math performance. Ramirez et al. (2018) took a slightly different approach, citing evidence from the study on social stereotype by Goetz et al. (2013), which reported trait and state-level anxiety of female and male students from grades 5 through 11. The results showed that females self-report higher math anxiety (trait) than males; however, no difference was seen while reporting real-time math anxiety before and during a math exam (state). Ramirez et al. (2018), using an interpretation account, suggest that it is the math competency beliefs rather than actual math ability that has contributed to gender differences in math anxiety. An alternate explanation put forth by Ashcraft (2019) is that the internalization of societal and cultural attitudes and stereotypical beliefs, such as math being a male-dominated field or math for men, by women might made them feel inadequate in math abilities, resulting in math anxiety.

Caviola et al. (2017) pointed out that there is less knowledge about how gender-related differences in math anxiety develop among children as most of the studies are from the adult population. Based on OECD 2013 data, the authors mentioned statistics from Italy where, among girls, 48.5% reported high levels of math anxiety compared to 37.8% in the case of boys. Hill et al. (2016), in their investigation study on math anxiety among primary and secondary school students, have argued that though the literature suggests girls report more math anxiety than boys at both primary and secondary levels, the evidence of gender difference in math anxiety is more definitive among secondary school children. The authors speculated two plausible reasons: the lack of sufficient research at the primary school level and the gender differences in math anxiety could be more prominent and visible only at the secondary school level. Hill et al. (2016) investigated the issue, and their results corroborated earlier findings from the literature on girls scoring higher on math anxiety than boys. Their crucial finding indicated that the same pattern of gender difference was observed at secondary and primary levels when girls and boys were split according to their respective school levels. The next chapters will provide other possible factors and explanations for gender differences in math anxiety, including answers to questions such as what research has to say about the role of stereotype threat among observed gender differences in math anxiety.

# CHAPTER 2: FACTORS ASSOCIATED WITH MATH ANXIETY

Luttenberger et al. (2018) pointed out that math anxiety is neither linked to clinical research on anxiety disorders nor is it included as a separate category in the Diagnostic and Statistical Manual of Mental Disorders (DSM) and the International Classification of Diseases (ICD). Instead, its investigation is mainly confined to educational settings. Further, Luttenberger et al. emphasize that math anxiety cannot be studied in isolation mainly due to its immediate effect in math-related situations such as in the classroom or during examinations. Indeed, the authors view it as a variable within a collection of other interacting variables (individual and environmental). Specifically, they considered the role of mediating and moderating variables on math anxiety, where the latter refers to the strength and direction of the relationship between two variables, and the former explains how two variables are related. Because in their opinion, having in-depth knowledge regarding the development of math anxiety and its interaction with other variables is crucial in diagnosing and planning interventions. Therefore, this chapter will focus on the etiology of math anxiety, its internal and external factors, and related causes across math test anxiety, math learning anxiety, and math anxiety in daily life situations (Cipora et al., 2022).

## 2.1 External versus Internal Factors

The factors associated with math anxiety can be categorized as external and internal. The latter refers to individual factors and the former deals with environmental factors that are related to an individual. In the past, efforts have been made to understand the influence of these factors on math anxiety. For example, Ramirez et al. (2018) differentiated the causes of math anxiety into poor math skills, genetic predispositions, and socioenvironmental factors. Alternatively, Rubinsten et al. (2019) proposed a theoretical model explaining how environmental factors interact with an individual's intrinsic factors, such as attentional resources, increasing the risk of developing math anxiety. Similarly, Luttenberger et al. (2018) developed a framework for understanding math anxiety and its effects, considering the role of mediating and moderating variables.

According to Luttenberger et al. (2018), the variables are classified as:

- outcome variables that have persistent effects on developing math anxiety, such as performance, learning behaviors, or choices;
- antecedent variables that impact the occurrence of math anxiety include culture, educational system, attitudes and beliefs, gender, or trait anxiety;
- variables, such as self-efficacy, self-concept, and motivation in math, interact reciprocally with math anxiety.

### *2.11 Educational Factors*

Skemp (1986, as cited in Petronzi et al., 2019) regarded the development of math anxiety among children aged 5-6 due to classroom experiences and poor teaching styles. Similarly, Ramirez et al. (2018) discussed how teachers might foster students' math anxiety by employing pedagogical practices that lack conceptual understanding or rely on rote learning. Moreover, excessive curriculum demands might induce pressure on children and teachers, creating an ideal environment for anxiety (Petronzi et al., 2019). Conversely, Dowker et al. (2016) speculated that pre-existing difficulties in mathematical cognition and repeated exposure to failure in math due to poor math competencies might lead to math anxiety. As already discussed in the first chapter, having teachers who suffer from math anxiety might increase the risk of developing math anxiety among students. Considering the examination scenario, Dowker (2019) indicated a stronger math anxiety reaction for timed tests than untimed ones.

At an individual level, when children in early education underperform in math, Petronzi et al. (2019) mention how negative evaluations from others in school might lead to evaluation anxiety. The authors found that worrying about working with numbers (numeracy apprehension) in early education might be an antecedent of math anxiety. Other studies, such as Caviola et al. (2021) and Donolato et al. (2020), found that general anxiety and test anxiety might act as risk factors and can be essential precursors in the development of math anxiety. Lastly, Gunderson et al. (2018, as cited in Petronzi et al., 2019) provide evidence that low math achievement among students at the beginning of first and second grade anticipated high math anxiety later at the end of the school year.

### *2.12 Social and Developmental Factors*

Bosmans and De Smedt (2015) highlighted the importance of considering insecure attachment while studying math anxiety. They reported that insecurely attached children are more inclined to have math anxiety and, consequently, are at risk of performing poorly on math tasks. Although the study focused on children's attachment only to their mothers, it underscores the importance of insecure attachment while understanding the origins of math anxiety. Further, in the development process, an individual who is prone to general anxiety (i.e., trait anxiety) might likely develop math anxiety, especially test and classroom math anxiety (Luttenberger et al., 2018). However, Dowker et al. (2016) argue that it is both negative experiences with math and genetic risk factors based on math cognition and anxiety that might contribute to the development of math anxiety. Indeed, as already discussed, about 40% of the variance in math anxiety is due to genetic factors, and the rest is assumed to be non-shared environmental factors (Wang et al., 2014, as cited in Dowker et al., 2016). Finally, there is some evidence from intergenerational studies based on complex family dynamics that parents' educational level might potentially contribute to their children's math anxiety (Vanbinst et al., 2020).

Gender is considered a crucial factor in the development of math anxiety, as research has often suggested that girls have an increased predisposition towards higher math anxiety levels than boys (Szűcs & Mammarella, 2020). One frequently reported reason in those studies was societal stereotypes about capability and desirability for STEM-based careers. For instance, Dowker et al. (2016) explain the role of stereotype threat (risk to validate a negative stereotype attached to a group to which an individual belongs) specific to the domain of math anxiety, wherein females often face the stereotype that math is a male-dominant field, or males are better for STEM-based careers than females, which might explain higher levels of math anxiety among females.

Dowker et al. (2016) speculate that math anxiety might increase with age because general anxiety rises with age. Simultaneously, the possibility of being exposed to negative attitudes towards math by significant others, experiencing social stereotypes, and heavy demands from the curriculum all accumulate with age, which might elevate math anxiety in return. However, Ramirez et al. (2018) argue that there is no sufficient evidence math anxiety accumulates over time. This hints that some factors might protect against math anxiety. Therefore, as Ramirez et al. emphasize, more studies on developmental trajectories of math anxiety are essential in identifying those favorable factors at the individual level.

### *2.13 Behavioural and Emotional Factors*

Emotional factors related to math anxiety are classified under the affective dimension accompanied by behavioral consequences. Most factors under this sub-section are reciprocal variables related to math anxiety, such as self-efficacy, self-concept, and motivation (Dowker et al., 2016).

According to Rubinsten et al. (2018), math self-efficacy is one's self-belief about achieving successful outcomes in reducing math anxiety. Studies on math-related emotions showed a reciprocal relation between self-efficacy and math anxiety, wherein higher self-efficacy correlated with lower math anxiety ($r$ = -0.4) (Živković et al., 2023). In another study, Ahmed et al. (2012, as cited in Ramirez et al., 2018) provided evidence for the reciprocal relationship between math anxiety and math self-concept. The authors found that the direction of the relationship from math self-concept to math anxiety was more significant than the other way around. However, Dowker et al. (2016) urge caution while considering these results as the longitudinal study by Ahmed et al. was for a short duration (one school year).

Meanwhile, Szűcs and Mammarella (2024), considering the relationship between math motivation and math anxiety, disagreed with the idea that students with high math anxiety are less motivated towards math. Moreover, the authors specified that highly motivated students might be more likely to experience test math anxiety but less likely to experience learning math anxiety. They found that girls, compared to boys, often exhibited lower math motivation in combination with higher math anxiety.

Finally, learning behaviors such as avoidance and procrastination have significantly contributed to establishing a vicious cycle in which students with math anxiety avoid participating in math activities or procrastinate. Going further, these students might perform below expectations on tests, ultimately resulting in even higher levels of math anxiety than earlier (Luttenberger et al., 2018).

### *2.14 Cognitive Factors*

Ramirez et al. (2018) established a consistent negative relation between math competency and math anxiety through their research work. With reduced competency account, they found that poor math skills contribute to the later development of math anxiety. In another line of study, Necka et al. (2015, as cited in Morsanyi et al., 2016) assessed to what extent an individual's cognitive representations of math overlap with self (which they termed *self-math overlap)* might relate to one's feeling of math anxiety. In a nutshell, the authors in the study demonstrated that incorporating math into one's sense of self would predict diminished levels of math anxiety.

Maloney and Beilock (2012) discussed how cognitive predispositions (thought patterns, beliefs, and attitudes) related to math might facilitate the onset of math anxiety as early as elementary school. Furthermore, Morsanyi et al. (2016) summarized that controlling irrelevant information and retrieving facts were good predictors in identifying individuals with high or low math anxiety. However, the authors stated that this conclusion was based on studies that compared extreme groups, that is, high versus low math anxiety.

In conclusion, Math anxiety is a product of the dynamic interplay between individual or personal factors (predispositions, beliefs, attitudes) and environmental factors (both mediators and moderators), which changes across the temporal line (Rubinsten et al., 2018). According to Petronzi et al. (2019), one cannot be sure about the causality of the abovementioned factors because of insufficient research to determine whether math anxiety is the cause or effect. Therefore, researchers often agree that more longitudinal studies with young children are needed to understand better the origins of math anxiety (Morsanyi et al., 2016). Considering the above arguments, thinking that math anxiety is always detrimental to math learning is viable. However, research work by Wang et al. (2015) provides an insight that having moderate levels of math anxiety is profitable rather than damaging only if an individual is intrinsically motivated to do math (will be discussed in the following sections).

## 2.2 Math Anxiety and Protective Factors

According to Mammarella et al. (2018), protective factors are the features or characteristics that foster successful development and help reduce unfavorable outcomes or risk factors. These factors are crucial in math achievement as they protect against math anxiety (Szűcs & Mammarella, 2024). Additionally, Ramirez et al. (2018) discuss that appraising these personal resources or protective factors in stressful academic situations might help an individual interpret those demands as challenging, which indeed might facilitate performance. Moreover, Mammarella et al. (2018) consider that focusing on general and academic personal protective factors helps in understanding the development of an individual in relation to these factors. In this sub-section, personal protective factors against math anxiety, such as self-concept, self-efficacy, and resilience, will be addressed.

With an interpretation account, Ramirez et al. (2018) discussed how high math self-concept and self-efficacy positively influence students' appraisals of their math experience, preventing dysfunctional interpretations. The authors also explained how lower self-concept results in a negative appraisal of math ability, leading to math anxiety because of ineffective schemas applied in the first place. Additionally, Živković et al. (2023) showed that math self-efficacy is positively correlated to enjoyment in math (positive emotion) and is negatively correlated with math anxiety (negative emotion). Further, the authors state that an increase in math efficacy might act as a protective factor while learning math, making students resilient to the hindering effects of math anxiety.

Caviola et al. (2022) define *resilience* (ego-resiliency) as a group of distinct characteristics of an individual that help combat everyday life challenges. Considering previous studies, the authors reported a positive association between ego resiliency and academic achievement. The results of their research showed a negative association of ego-resiliency only with general anxiety, excluding test or math anxiety. However, the authors emphasized the protective role of ego-resiliency against worrisome thoughts related to students' performance, thus helping to reduce any school anxieties (i.e., math or test anxiety).

### 2.3 Note on Individual Differences in Math Anxiety

Petronzi et al. (2019) consider math anxiety as a continuum rather than categorical (i.e., having or not having one). However, the authors agree that specifying the number of negative experiences that lead to higher math anxiety is difficult. In their opinion, some individuals might develop math anxiety rapidly, whereas others might be resilient and need more negative experiences, if at all, to be math-anxious. In this way, Petronzi et al. provide a new perspective highlighting the relative aspect of math anxiety with respect to individual differences. Similarly, Szűcs and Mammarella (2024) present a case on how, despite sharing similar school experiences, individuals with low and high math anxiety differ in their subjective interpretations of those experiences. For example, Mattarell-Micke et al. (2011, as cited in Ramirez et al., 2018) suggest a difference in the interpretation of heightened physiological reactions among individuals with low and high math anxiety. In the case of low math anxiety, it is interpreted as a cue of being in a challenging situation, which might boost the individual's performance. In contrast, a high math anxiety case might signal it as math-related distress, leading to worries and subsequent poor performance. Lastly, Wang et al. (2015) provide evidence against all anxiety being detrimental. The authors found an inverted U relationship between math anxiety and math performance under high intrinsic motivation for math. Alternatively, individuals with low intrinsic motivation for math showed a negative correlation. In summary, mild levels of math anxiety among individuals facilitate better math performance only when accompanied by high intrinsic motivation, highlighting individual differences (Petronzi et al., 2019).

# CHAPTER 3: EMPIRICAL EVIDENCE OF MATH ANXIETY

## 3.1 Children with and without Mathematical Disability- Comparative Study

Research has suggested the involvement of cognitive and/or emotional difficulties in math learning. Consequently, poor performance or failure in math can be attributed to either cognitive difficulties, such as specific learning disability in math (developmental dyscalculia), or the presence of an emotional issue, such as math anxiety. In classroom situations, students with high math anxiety might often be grouped with those having disability in learning math, as both conditions lead to poor performance in math. Nevertheless, the underlying reasons or factors differ; developmental dyscalculia is due to cognitive deficits in math with normal general mental ability, reading, and writing, whereas math anxiety results from emotional factors (Caviola et al., 2019; Mammarella et al., 2015). Until recently, there was speculation about a causal relationship between mathematical learning difficulties and math anxiety (Dowker et al., 2016). However, Cipora et al. (2022) stated that math anxiety and mathematical learning difficulties are independent but might have some co-occurring conditions.

This subsection presents the results from studies that compare the math anxiety of children with and without math learning disability regarding their performance in math. On one side, some studies focused on the prevalence of comorbidity between developmental dyscalculia and math anxiety. Others concentrated on separating specific cognitive profiles between children with math anxiety and developmental dyscalculia (Caviola et al., 2019).

Devine et al. (2018) examined the comorbidity of math anxiety and math learning difficulties among 1,757 primary (8-9 years) and secondary school children (12-13 years). They termed math learning difficulties as mathematical learning impairments of developmental origin, such as developmental dyscalculia. In contrast, math anxiety was considered an adverse emotional reaction to math tasks that can be present in children with and without math learning difficulties. The authors found that there was a two-fold increase in the development of high math anxiety among children with developmental dyscalculia (22%) compared to typically performing children in math (11%). The study also reported that about 78% of the children with developmental dyscalculia did not show high math anxiety. Possible reasons for the latter, as speculated by authors, include children not having high expectations from their performance in math, not perceiving math as essential, or not having the necessary metacognitive skills to evaluate math abilities. Though the study found an equal prevalence of developmental dyscalculia among boys and girls, its comorbidity with math anxiety was more significant among girls than boys (as seen in the case of math anxiety). Based on the observations, the authors concluded that there is a dissociation between cognitive and emotional problems related to math and that poor performance in math is solely due to high math anxiety.

Underscoring weak memory function as a common factor among children with developmental dyscalculia and those with high math anxiety, Mammarella et al. (2015) aimed to test whether the impairments affected similar memory systems among these groups. In their study with sixty-nine children aged 11-13, Mammarella et al. decoupled low arithmetic proficiency due to cognitive difficulties such as developmental dyscalculia and low math performance due to emotional aspects such as math anxiety. The authors compared the visuospatial and verbal short-term memory (STM) and working memory (WM) performance of children with developmental dyscalculia (low math performance and no math anxiety), math anxiety (low math performance and high math anxiety), and in control condition (typically developing children). The results showed that relative to children with typical development, those with developmental dyscalculia scored low on visuospatial WM tasks, and those with high math anxiety scored low on verbal WM tasks. At last, the authors concluded that math anxiety and developmental dyscalculia have different underlying factors

(Mammarella et al., 2015). In a successive study, Mammarella et al. (2018) focused on inhibitory mechanisms among 8-10-year-old children with math anxiety and those with or without developmental dyscalculia. It was found that children with math anxiety (without developmental dyscalculia) were more vulnerable to *proactive interference*, that is, the capability to resist obsolete information while focusing on a particular task. The results were consistent with the attentional control theory, specifying that impairment in processing efficiency due to diminished attentional control is caused by math anxiety (Mammarella et al., 2018).

The abovementioned studies highlight the critical role of math anxiety in poor math performance. Both studies emphasize the importance of understanding emotional and cognitive factors associated with math anxiety and developmental dyscalculia, which might help identify the reasons behind children's failure in math. Moreover, they recommend using different intervention methods to overcome emotional and cognitive barriers in math development (Devine et al., 2018; Mammarella et al., 2015).

### 3.2 Multidimensional Approach Studies

In school settings, it is not always straightforward to identify math anxiety caused by actual or perceived threats because of variations in individual responses to high-stakes or stressful situations related to math. Although self-reports or questionnaires are considered reliable measures of math anxiety, studies using other measures (psychological, cognitive, emotional, and behavioral) combined with questionnaires might help better understand those variations among individual responses while performing anxiety-inducing math tasks. Specifically, measures of math anxiety based on physiological responses might help overcome the limitations of self-reported data (Cipora et al., 2022). Another advantage of including the former measures is to capture the heterogeneity of the math anxiety construct, which might be helpful for differential individual diagnosis or in developing an adaptive intervention plan (Cipora et al., 2019). This subsection will present a study done by Mammarella et al. (2023) on multidimensional components of state-math anxiety, looking into students' behavioral, cognitive, emotional, and psychophysiological responses in achievement situations at school.

The study by Mammarella et al. (2023) aimed to analyze the effect of situational stress by manipulating feedback on behavioral responses (reaction time and accuracy), cognitive responses (competence and worry), emotional responses (arousal, valence, and control), and psychophysiological responses (skin conductance and heart rate changes) in a sample of 165 fifth grade students while performing a math task. The experimental design induced stressful situations to elicit state math anxiety by providing positive or negative false feedback to students after their response to mental calculations. Further, students were assigned to one of the three experimental conditions: positive (higher on positive feedback), negative (higher on negative feedback), or control group (received no feedback), and they were blinded to this manipulation. Questionnaires on students' emotional and cognitive state of math anxiety were collected before and after the math task, and students' physiological responses were recorded for the entire task duration. The authors tested the multidimensionality of triggered state math anxiety by short exposure to perceived failure in math tasks.

The results showed that, under behavioral response, students' performance in the control condition was significantly lower compared to the other two groups. Mammarella et al. (2023) speculated that students in the control group might have put little effort into the math task as no feedback was given. The students in the control group also showed minimal physiological responses, suggesting that the absence of feedback might have led to lower engagement in math tasks. Consequently, this might have resulted in low stress levels, further leading to behavioral responses such as low accuracy and longer reaction time compared to other groups. The authors concluded that the minimal skin conductance responses by the control group might have affected their behavioral responses to math tasks negatively. On the other hand, students in positive and negative groups were more accurate in math tasks, with faster responses from the positive group. The authors indicated that positive and negative feedback might favor boosting accuracy compared to no feedback conditions.

Although the negative group had favorable behavioral responses, a different pattern was seen when considering emotional, cognitive, and physiological responses. Mammarella et al. (2023) explain that despite receiving negative feedback, the student's performance in math tasks was not affected at the behavioral level. However, students in this group showed a lower sense of control than those in the positive and control groups. They also reported reduced competence in math tasks and an overall increase in worry compared to the other two groups. Though the skin conductance response was similar in both positive and negative groups, the authors speculated that having marked vagal withdrawal (parasympathetic deactivation with increased heart rate) in the negative group for an extended period might lead to adverse outcomes such as anxiety. Consequently, the authors suggested that sympathetic responses such as skin conductance alone are not sufficient to understand physiological responses under stress. For instance, the authors explain that in a demanding situation like a math task, a moderate sympathetic activation (moderate increase in skin conductance) associated with a moderate parasympathetic deactivation (moderate vagal withdrawal) would likely lead to better performance in math task (optimum behavioral response). Moreover, the authors report that children with moderate vagal withdrawal performed better than those with no vagal withdrawal.

In conclusion, the study by Mammarella et al. (2023) provides evidence that relying on behavioral data alone might brief about superficial effects such as changes in performance after repeated exposure to feedback conditions. However, considering other responses, such as emotional, cognitive, and physiological, might reveal deeper aspects like negative feelings, weaker sense of control, worrying, lower perceived competence, and marked vagal withdrawal, which indeed is essential in understanding math anxiety.

### 3.3 Performance and Intervention Studies

According to Dowker (2019), intervention studies might reveal the most compelling evidence for the bidirectional relationship between math anxiety and performance. In other words, the author indicates that interventions used to enhance either factor can lead to improvements in the other. Therefore, the studies under this subsection are divided into two categories: studies focusing on interventions to improve math performance by addressing underlying math anxiety (without enhancing math skills) and another set of studies focusing on interventions to improve students' math performance by enhancing math skills, which might eventually reduce math anxiety.

Under the first category, Ramirez and Beilock (2011) developed an expressive writing technique to reduce intrusive thoughts among students with math anxiety and improve their performance. The authors investigated expressive writing as a psychological intervention in laboratory conditions. They hypothesized that if poor performance on math tests was due to worries and if expressive writing alleviates the burden placed on working memory by reappraising those worries, then students who tend to worry the most during testing situations should benefit from this writing intervention. In the laboratory experiment, students were exposed to low or high levels of performance pressure while taking a math test. They were assigned either to a control group (sitting quiet or unrelated writing) or a writing intervention group (expressive writing). The latter group was asked to write freely about their feelings and thoughts on the math test they would take. Though the pretest math performance did not differ across the groups, it was found that control group students sitting quietly experienced a 12% drop in performance from pre- to post-test, and those involved in unrelated writing showed a decline of 7%. On the other hand, students in the expressive writing group showed a 5% increase in performance from pre- to post-test. The authors reasoned that the difference in performance drop within the control group (sitting quietly vs. unrelated writing) might indicate that writing, regardless of the content, would reallocate the attention from the situation and thus improve performance compared to not writing at all. However, the authors found that students in expressive writing used more anxiety-related words and revealed more negative thoughts on math tests compared to those in unrelated writing group.

Additionally, Ramirez and Beilock (2011) carried out a randomized field experiment that tested the same intervention on ninth-grade students before and after their final exam. It was found that after the intervention, high-test anxious students who expressively wrote outperformed the control group by 6% and performed equally as low-test anxious students regardless of writing condition. Conversely, no difference emerged due to writing conditions among students with low test anxiety. In conclusion, the authors demonstrated that a brief (10 min) expressive writing intervention might help boost performance during high-pressure testing situations such as math, especially for students who are habitually anxious about taking the tests.

Under the second category, Supekar et al. (2015, as cited in Dowker et al., 2016) tested the efficacy of an intervention to improve the math skills of students aged 7-9 years. Students underwent an intensive one-to-one math tutoring program for 8 weeks split into three sessions (40-50min) per week. The authors used the Scale for Early Mathematics Anxiety (SEMA) to report math anxiety levels along with an fMRI scan before and after the training. The students were assigned either a control task (number identification) or an addition task (solving an arithmetic problem) while having an fMRI scan. The authors reported that one-on-one math tutoring helped reduce math anxiety scores and altered abnormal brain responses and connectivity in emotion-related pathways associated with the amygdala. The latter changes were seen among students who were high on math anxiety but not among those low on math anxiety. More importantly, it was found that students who presented reduced amygdala activity through tutoring subsequently scored lower on the math anxiety scale. Finally, the authors concluded that consistent exposure to math stimuli through short, intensive, one-on-one cognitive tutoring might reduce math anxiety by modulating neural functions (Dowker et al., 2016).

Although Ramirez and Beilock (2011) provided convincing results from field experiments with an actual math test, Dowker et al. (2016) share some speculations on its validation and express the need for verification in the future. As far as the study by Supekar et al. (2015, as cited in Dowker et al., 2016) is concerned, they provided proof of the potential effectiveness that combining behavioral interventions simultaneously with neural and cognitive assessment might help in understanding the efficacy of interventions according to individual differences. However, Dowker et al. seek caution while considering the findings because students in this study were categorized using an extreme group approach (high vs. low) through the median split of SEMA scores, which might affect the interpretations.

### 3.4 Studies Focusing on Types of Anxiety and Student Profiles

According to Caviola et al. (2021), the two most often studied forms of academic anxiety are math anxiety and test anxiety, which are consistently associated with various aspects of maths. Thus, the authors consider it essential to clarify the effect math and test anxiety pose on math performance under different sub-domains of math. Therefore, in one of the meta-analytic studies, Caviola et al. (2021) examined the effect of these forms of anxiety by differentiating types of math tasks. The authors found a stronger negative correlation ($r$ = -

0.31) between math anxiety and advanced math domains necessitating multistep processes compared to primary math domains (early numeracy) ($r$ = -0.22), which do not necessitate multistep processes. Further, the authors identified that the type of math task strongly influenced the strength of this association in math anxiety studies compared to test anxiety studies. Additionally, Hill et al. (2016) concluded that math anxiety is not linked to reading performance or any other academic domains in general but is exclusive to maths when controlled for general anxiety among primary and secondary students.

In another study, Mammarella et al. (2018) used latent profile analysis to examine different anxiety profiles among 664 school children in grades 3 to 6. In their opinion, rather than simple correlations, latent profile analysis would help identify heterogeneous subgroups with specific anxiety patterns. The authors identified three different profiles based on math, test, and general anxiety levels. The results of the study showed that around 12% of the students had a low-risk profile (low scores in various forms of anxiety), and around 66% had an average-risk profile (high scores on general and math anxiety but low on test anxiety). Lastly, around 22% revealed a high-risk profile (high scores on general and test anxiety but low on math anxiety). Through their analysis, the authors emphasized that forms of anxiety start to differentiate between 3rd and 6th grade, and general anxiety appeared to be a potential risk factor for the onset of more specific anxiety forms.

Lastly, Passolunghi et al. (2016) focused on high or low levels of math anxiety among students (grade 6 to 8) to investigate their profiles in different cognitive and academic achievement areas. The former included verbal short-term memory (STM) and working memory (WM), and the latter focused on reading (decoding and comprehension) and math achievement. Regarding academic achievement, the study showed that students with high math anxiety were at a greater risk of performing poorly on almost all math tasks (except appropriate calculation subtest) compared to those with low math anxiety. Moreover, no group difference emerged in reading (decoding and comprehension). Further, the authors stated that students with high math anxiety performed poorly in verbal STM and WM tasks and displayed less inhibition towards irrelevant information. Finally, the authors concluded that inhibitory control and fact retrieval measures are good predictors for identifying students with high or low math anxiety.

**3.5 Cross-cultural Studies**

Test anxiety has been studied among various cultures, and findings indicate that it is a frequent phenomenon across cultures. On the other hand, cross-cultural research related to math anxiety is very scarce, and little is known about its generalizability across different cultures (Lee, 2009). Instead, much is studied about the relationship between math performance and variables related to attitudes and beliefs about math. For example, the latter studies found differential patterns in attitudes among Asian and American students toward math and math achievement (Ho et al., 2000, as cited in Lee, 2009). Thus, the negative association between math anxiety and achievement, which emerged in the international evaluation studies such as PISA, might vary across/or within cultures (OECD, 2013). Moreover, Lee (2009, as cited in Dowker et al., 2016) found inconsistencies among the overall math achievement levels and average math anxiety scores of some countries, possibly due to differences in the etiology of math anxiety across cultures.

In one particular cross-cultural study, Fan et al. (2019) explored profiles of math anxiety among 11,003 students aged 15 years from Finland, Korea, and the United States using PISA 2012 data. They used multi-group latent profile analysis (MGLPA) to identify cultural similarities and differences in math anxiety across the samples. The authors reported three math anxiety profiles: low math anxiety (LMA), Mid math anxiety (MMA), and high math anxiety (HMA) among all three national samples. Further, the authors found that the percentage of students under each profile significantly differed across the three nations. Concerning the prevalence of HMA, the United States has the highest prevalence, and Finland has the lowest. Alternatively, MGLPA provided distinct latent profile separation wherein students with HMA among all the three national samples had significantly poor performance in math and low math interest (self-efficacy and self-concept). Through their findings, the authors implied that there is a possibility of a certain relative level of universality in math anxiety among the sample, irrespective of cultural context. Lastly, Fan et al. emphasized MGLPA as a potential analytic tool that could be used for classification in future cross-cultural studies on math anxiety.

Though the symptoms of math anxiety are similar across cultures, its expression considerably varies as a function of mathematical concerns specific to a given culture (Rubinsten et al., 2018). Meanwhile, a cross-cultural perspective on a psychological construct such as math anxiety would help evaluate the replicability and generalizability of its correlational results with other variables. Alternatively, this could provide a better understanding of why some individuals, despite high math anxiety, score high on math tasks or those with low math anxiety still score low on math tasks (Dowker et al., 2016).

### 3.6 Mathematics Resilience as a Protective Factor

Resilience, in general, is considered a crucial personal factor that protects against anxiety. According to Mammarella et al. (2018), resilience (both general and academic) is negatively associated with a high anxiety risk profile (that is, students with high levels of general and test anxiety but with low levels of math anxiety). However, Caviola et al. (2022) showed a negative association of ego-resiliency (resilience) only with general anxiety, excluding test or math anxiety. In either case, resilience, in general, might not have a promising protective effect on individuals with high math anxiety. Similarly, Lee and

Johnston-Wilder (2017) specify that individuals who are resilient in various aspects of their lives might often still be resistant or unwilling to expand that resilience in math learning. Thus, the authors emphasize the need for a specific notion of mathematics resilience. Through pragmatic argument, the authors describe mathematics resilience as a positive construct that enables students to develop a positive stance toward learning math. In the authors' opinion, mathematics resilience would allow individuals to manage and protect themselves from adverse emotional outcomes like math anxiety as the subject becomes challenging to learn.

According to Lee and Johnston-Wilder (2017), constructs such as math avoidance and anxiety mainly focus on the negative consequences of math learning and performance. Also, they state that the research focusing on these constructs has majorly offered interventions once the problem has developed. Instead, they believe that focusing on protective factors like mathematics resilience might help prevent the development of negative emotions toward math in the first place. Lee and Johnston-Wilder consider mathematics resilience not to be an inherent trait limited to particular individuals. Instead, they believe it can be developed in the process of learning maths as there is sufficient evidence that an individual can acquire or learn to be resilient with proper support (Caviola et al., 2022). Moreover, there has been an increase in research studies dedicated to mathematics resilience, beginning in 2017 and peaking around 2020-2021, indicating its growing need and acknowledgment (Akkan & Horzum, 2024). Therefore, with the above arguments, it is adequate to consider mathematics resilience as a potential protective factor against math anxiety.

# CHAPTER 4: FURTHER DEVELOPMENTS

Lee and Johnston-Wilder (2017) emphasize that anxiety and avoidance are likely to be acquired, either directly (primary experience) or through secondary experiences, such as involving in talks with others about negative experiences related to math. With the worldwide prevalence of a common negative stance towards math, as evident from the PISA study, the authors draw attention for an immediate need to recognize and develop protective factors against math anxiety. One such personal factor that has gained increased attention in psychological and educational research is mathematics resilience. Additionally, recent developments in the study on math anxiety adopted an alternate perspective of enhancing personal factors that might prevent the onset of negative emotions towards math in the first place rather than solely depending on interventions focusing on how to deal with cognitive and emotional aspects of math anxiety (Johnston-Wilder & Lee, 2010).

In a systematic review, Xenofontos and Mouroutsou (2023) found that mathematics resilience at an individual level is conceptualized as the coexistence of high math performance and disadvantaged characteristics (low socioeconomic status, minoritized ethnic background) on one side and as part of one's math identity on the other. Moreover, the study reported that psychological and socio-environmental factors influence mathematics resilience. Based on these factors, the authors delineated approaches towards mathematics resilience specific to marginalized individuals where resilience is associated with social constructs (racial stereotypes and expectations) on one side and resilience through the lens of psychology on the other. Indeed, the initial research on resilience from the field of psychology (Mammarella et al., 2018) has influenced the work of educational researchers, ultimately providing insight into the concept of mathematics resilience (Xenofontos & Mouroutsou, 2023). This chapter discusses the concept of mathematics resilience, focusing on psychological characteristics such as anxiety, growth mindset, motivation, and self-efficacy, mainly through the work of Johnston-Wilder and Lee.

### 4.1: Mathematics Resilience and Individual Difference

Johnston-Wilder and Lee (2010) believe that a certain level of resilience is required for any form of learning. However, the authors assert that the resilience involved in learning math has to be a specific one, which they termed mathematics resilience. As previously mentioned, mathematics resilience refers to a positive stance taken by an individual towards math despite challenges and adverse outcomes faced in the process of learning math. The authors advocate for a separate construct of mathematics resilience due to distinct obstacles an individual might confront while learning math, such as teaching style that promotes rote learning, common assumptions about the fixed nature of math ability, and the nature of math itself (Johnston-Wilder & Lee, 2010). Lastly, Lee and Johnston-Wilder (2017) underscore the importance of mathematics resilience by illustrating how the underlying ideas of a fixed mindset, anxiety, avoidance, and helplessness in math might result in a society that normalizes math avoidance, reinforcing the stereotype that willingness and ability to engage in math is confined to elite few.

#### *Growth Mindset and Self-Determination in Mathematics Resilience*

Providing a historical reference, Johnston-Wilder and Lee (2010) mention that mathematics resilience has its roots in the work of Carol Dweck (2000, as cited in Johnston-Wilder & Lee, 2010) on the theory of fixed and growth mindsets. The former refers to a notion of considering an individual's intellectual abilities as fixed beyond which they cannot grow. In contrast, the growth mindset emphasizes the ability of an individual to grow and develop the required skills in the face of adversity. Additionally, an individual with a growth mindset believes that abilities and skills can be improved and developed through effort. Ramirez et al. (2018, as cited in Oszwa, 2022) put forward a similar view, suggesting interventions to help an individual develop a growth mindset that would promote a constructive interpretation of negative experiences related to math learning. Therefore, an individual's mindset could be one of the key factors in developing mathematics resilience (Oszwa, 2022).

Another crucial element in developing mathematics resilience is self-determination. Johnston-Wilder et al. (2021) proposed the use of Self-Determination Theory (SDT) in addressing math anxiety by fostering mathematics resilience. SDT (Deci & Ryan, 1985, as cited in Oszwa, 2022) considers basic psychological needs such as autonomy (regulate actions by interests and values), competence (feel effective in capacities), and relatedness (feel valued, connected, and sense of belonging) to be crucial in fostering intrinsic motivation along with an individual's personal growth and development. Therefore, individuals with self-determination would exhibit high autonomous motivation consistent with their intrinsic goals, enhancing responsibility towards the learning process (Johnston-Wilder et al., 2021). Indeed, both theories ensure the improvement of an individual's attitude towards overcoming difficulties while learning math through efforts and preserving the intrinsic motivation necessary to pursue future education in math or STEM subjects (Oszwa, 2022).

Lastly, using SDT, Johnston-Wilder et al. (2021) formulated that math anxiety might result in an individual who is deprived of the basic psychological needs mentioned above. Although SDT focuses on autonomous motivation, the authors clarified that it does not provide the necessary tools to meet those needs. Instead, the authors illustrated how tools of mathematics resilience could be used to meet those needs and improve an individual's willingness to engage in learning by reducing math anxiety. The four aspects (tools) outlined by Johnston-Wilder et al. associated with mathematics resilience are as follows: the personal value of math (autonomy), growth mindset (competence), community (relatedness), and an understanding of managing emotions while working at math (struggle). The latter is considered a key aspect in learning math because realizing that a certain amount of struggle is inevitable in math might help in learning to manage anxiety if and when it arises.

### *Mathematics Resilience and Related Constructs*

An overview study by Ishak et al. (2020) differentiated the terms resilience, academic resilience, and mathematics resilience by analyzing the concept of resilience in maths subject. The authors reported math anxiety and learner helplessness as the issues exclusively tackled by mathematics resilience. Alternatively, resilience mainly tackles individuals at risk concerning their family background, race, identity, and income. In contrast, academic resilience deals with an individual's family background and school environment. Lastly, the authors emphasized mathematics resilience as one of the potential solutions to math anxiety problems (Cropp, 2017, as cited in Ishak et al., 2020).

According to Lee and Johnston-Wilder (2017), self-efficacy (belief in an individual's ability to succeed in specific situations) plays a significant role in the development of mathematics resilience. Many individuals who display math avoidance behavior often believe that they cannot do math, mainly due to low self-efficacy in math. Consequently, having a higher sense of self-efficacy might help an individual perceive challenging problems in math as an opportunity for improving and acquiring skills for the future (Lee & Johnston-Wilder, 2017). Meanwhile, optimism is also strongly related to resilience, which is required in learning math. Lee and Johnston-Wilder indicate that Seligman (1995) views optimism (persistence and perseverance) as a form of resilience, a psychological characteristic common among individuals who display problem-solving ability, which is very important in math learning.

Although persistence and perseverance are essential for mathematics resilience, Oszwa (2022) differentiates perseverance as knowing when to continue without giving up too soon, trying alternate strategies, and seeking support when needed. Similarly, Lee and Johnston (2017) consider persistence alone is not enough to develop mathematics resilience; instead, they believe perseverance is more important, especially when dealing with a subject like math. Oszwa (2022) concludes that an optimistic individual attributes failure in math as temporary, specific to the situation, and related causes to be external rather than internal to the individual, which would facilitate overcoming helplessness while learning math.

Lastly, Lee and Johnston-Wilder (2017) highlight the significance of motivation in math learning and in developing mathematics resilience. Specifically, the authors argue that an individual with intrinsic motivation might feel connected, be effective, and experience feelings of agency and control while learning math, eventually developing mathematics resilience. To summarize, Lee and Johnston-Wilder state that individuals with mathematics resilience have a growth mindset, a high sense of self-efficacy, intrinsic motivation, optimistic confidence, and lower levels of math anxiety. Furthermore, the authors believe all the above factors would bring an individual closer to understanding the personal value of learning math by managing negative emotions if they arise.

### ***Research Studies on Mathematics Resilience***

Akkan and Horzum (2024), through a systemic review of 31 articles from 2000 to 2021 addressing mathematics resilience, reported that most of the studies were conducted in Indonesia and the United Kingdom, with the primary focus being high school students. The study also revealed that the research method used was predominantly qualitative. In the investigation, the authors found various dimensions of mathematics resilience encompassing cognitive (math skills and competence), affective (that influence success and psychology), pedagogical (teaching methods, interventions, and teacher characteristics), demographic (group characteristics), and social (family, peer, teachers, educational settings) domains. The authors speculate that an increase in research on mathematics resilience might be due to its immediate necessity and significance in psychology and education. For instance, the significant amount of research articles on mathematics resilience in Indonesia (14 out of 31) might be due to difficulties faced by its educational system, as reported by the PISA study on anxiety and performance of Indonesian students related to math (OECD, 2013).

For a comprehensive understanding of mathematics resilience, Akkan and Horzum (2024) recommend adopting quantitative methods with large sample sizes in future research. Furthermore, the authors pointed out the need for future research on the development of mathematics resilience from an early age for a deeper insight. Studies in this review have shown a positive correlation between mathematics resilience and problem-solving skills. Similarly, a positive correlation was found between motivation, metacognitive strategies, and mathematics resilience. However, the authors seek caution because the correlations mentioned above might not be linear and highly susceptible to individual differences and contextual factors. Lastly, Akkan and Horzum state that mathematics resilience is multifaceted (like math anxiety); therefore, the authors propose that more longitudinal research is required to understand the correlation of mathematics resilience with other cognitive and affective factors related to math. Furthermore, the authors emphasize that future studies should consider the role of external and internal factors in shaping an individual's resilience in math, which might help in planning interventions.

In conclusion, as Johnston-Wilder and Lee (2010) specify, mathematics resilience is considered crucial and unique to other resilience because it facilitates the mathematical functioning of an individual in the world beyond school. Moreover, Johnston-Wilder et al. (2021) emphasize that mathematics resilience provides necessary tools to help an individual focus on and become aware of emotions and physiological responses and in turn reappraise this information constructively (as a challenge rather than a threat). This interpretative differentiation (similar to the interpretation account by Ramirez et al., 2018) might help an individual overcome anxiety and try alternate choices rather than avoiding math altogether. Specific to math achievement across countries, Oszwa (2022) suggests that having mathematics resilience appears to prevent the onset of math anxiety and consequently might result in higher math achievement. Lastly, if mathematics resilience is of such significance, as Johnston-Wilder and Lee (2010) contemplate, why is there a global delay in gathering systematic empirical evidence on mathematics resilience?

# CONCLUSION – REFLECTIONS AND SUGGESTIONS

Throughout this thesis, an attempt has been made to provide a comprehensive understanding of math anxiety. The initial chapters focused on the correlation between math anxiety and other individual factors, specifically math performance, through the influential work of Hembree (1990). Meanwhile, the work of Ashcraft and colleagues (2001) provided insight into the role of working memory among those correlations. Further, the studies involving developmental perspectives, such as the review article by Dowker et al. (2016), Hembree's (1990) meta-analysis summarizing the trajectories of math anxiety across various age groups, and the work of Caviola et al. (2021), highlighted how math anxiety changes with age. Moreover, the apparent role of social stereotypes, especially with regard to gender, has offered an in-depth understanding of the reasons behind the global prevalence of gender differences in math anxiety. The thesis also discussed possible ways to mitigate math anxiety through the persuasive work of Ramirez et al. (2018), for instance, interpretation/appraisal account and expressive writing interventions, to name a few. Overall, addressing the different aspects of math anxiety, may it be various constructs, perspectives, dimensions, factors/causes, types of anxieties, and associations/correlations, all have contributed significantly to understanding and attempting to solve the math anxiety puzzle. Moreover, this thesis underscores the importance of integrating research findings from various dimensions, such as behavioral, neurobiological, cognitive, and socioenvironmental, to have a more vivid account of math anxiety that varies among individuals (Dowker et al., 2016).

However, as often mentioned in the literature, there is still a need for more interdisciplinary, longitudinal, and intervention studies for greater clarity on the interaction (mediation and moderation) of variables or factors associated with math anxiety (Dowker et al., 2016). At this point, it is crucial to reflect on how longitudinal studies on math anxiety might help in completing the puzzle. One possible outcome of longitudinal studies is delineating the cause-effect relationship of variables associated with math anxiety. Specific to a developmental perspective, the above studies might help see how math anxiety changes among individuals as they grow, which might further help in gathering additional information on the etiology of math anxiety. Lastly, as Ramirez et al. (2018) speculate, longitudinal studies might help to trace the developmental trajectory of math anxiety, which might help to formulate measures for assessing individual differences in math anxiety more accurately. As the authors speculate, doing so could ultimately result in sustainable intervention plans.

The literature so far has documented possible sources of individual differences in math learning. Equally, more emphasis must be placed on exploring individual differences in math anxiety in the future studies. Although the research has provided ample individual characteristics, an exhaustive list is yet to be established in formulating individual anxiety profiles and tailoring interventions for math anxiety. Lastly, as Cipora et al. (2019) suggest, we need a reliable and valid measure that captures the heterogeneity of the math anxiety construct, which might help in differential individual diagnosis and developing an adaptive intervention plan.

Considering the long-term consequences of math anxiety, such as avoidance behavior in math-related situations, it follows to ask whether educational settings should consider the consequences of math anxiety beyond its association with math performance. If yes, then why? In the long term, it is found that the effects of math anxiety are apparent on an individual's mental health and quality of life. Especially if the individual, despite math anxiety, decides to pursue math-related careers, might end up being at high risk for chronic stress or other mental/physical health conditions (Cipora et al., 2022). If not in math-related careers, an individual might otherwise be prone to making poor decisions on savings and finances, which would only increase the stress and add to the existing math anxiety. Recently, research has found the negative impact of math anxiety on consumer purchase decisions when faced with numerical and arithmetic calculations commonly encountered while shopping, turning what is supposed to be a joyful moment into an anxious one, directly hindering the quality of life. (Andersen et al., 2024). Alternatively, Rolison and Morsanyi (2015) found that math anxiety among individuals is associated with poorer medical risk interpretation. Specifically, it is more strongly related to confidence in interpretations and decision-making in the health domain. Though the thesis was confined to math anxiety among primary and secondary school children, it becomes a moral imperative to address it beyond school. Therefore, on a bigger scale, math anxiety is no longer limited to performance in math alone. Instead, more focus must be placed on measures to sensitize the community about the consequences of math anxiety in real-world scenarios.

According to Cipora et al. (2022), interventions to address math anxiety typically require one-to-one contact with a trained professional, which means considerable costs that are not easily implemented for all. Because of the latter reason, most intervention plans aimed to alleviate math anxiety at school are either short-term (questioning its effectiveness) or have not been replicated (questioning its reliability & validity). Alternatively, the idea of addressing math anxiety among school children must not be limited to safety behaviors such as relaxation techniques as part of temporary/situational relief. Instead, it should aim for long-term interventions through information exchange between researchers and educators. Stating the above points does not imply undermining the immense research work on interventions for math anxiety that has been done (Cipora et al., 2022). Instead, in the long term, this thesis suggests the need for further research to understand the role of potential protective factors in overcoming math anxiety. One such protective factor put forward is mathematics resilience. Although having interventions in place for math anxiety appears to be the standard action plan, this thesis believes preparing individuals to be math resilient from early on would be beneficial and economical in the long run. Nevertheless, it must be noted that the concept of mathematics resilience is relatively recent, and more work is yet to be done to translate it into practice. A good starting point would be to have a comprehensive understanding of mathematics resilience and build measurement instruments that can be used to assess it extensively among individuals.

After addressing all the aspects, the ultimate question remains: how close are we to filling the gap in unifying math anxiety research with real-world scenarios? In this regard, the Educational Practices Series on math anxiety by Szucs and Mammarella (2020) is noteworthy. The booklet comprises results of well-established, practically relevant contemporary research work from across the globe, translated into several languages. The advantage of having one such open source is that it foresees a well-connected educational community for better decision-making and intervention planning related to teaching, learning, and curriculum development addressing math anxiety. Moreover, the booklet might help individuals, especially parents/teachers, conceptualize math anxiety, not just by knowing what constitutes it but also by understanding what does not constitute math anxiety. Similarly, future research should focus on the creation and outreach of proper screening tools administered to children in school settings, which are easy to use, valid, and reliable to identify individuals who might be in the process of developing math anxiety. At the same time, caution must be paid not to misdiagnose or give unnecessary labels to children (Cipora et al., 2022)

Lastly, this thesis underscores the importance of addressing math anxiety from an early age through long-term interventions specific to and beyond school. Though the thesis briefly discussed research studies on math anxiety among children with and without developmental dyscalculia, it would be interesting to explore the learning process among mathematically gifted children and the prevalence of math anxiety (if it exists). To conclude, in the name of math anxiety, what we have is a constantly evolving puzzle that shapes our understanding and perception of it through emerging research. Therefore, further advancements in research (and a lot more data) from various perspectives on math anxiety are imperative in understanding and suggesting a remedy or solution to the puzzle.

## REFERENCES

(references marked with an asterisk (*) indicate articles not directly or partially referred)

*Aarnos, E., & Perkkilä, P. (2012). Early signs of mathematics anxiety? *Procedia - Social and Behavioral Sciences*, *46*, 1495-1499. https://doi.org/10.1016/j.sbspro.2012.05.328

Ahmed, W., Minnaert, A., Kuyper, H., & Van der Werf, G. (2012). Reciprocal relationships between math self-concept and math anxiety. *Learning and Individual Differences*, *22*(3), 385-389. https://doi.org/10.1016/j.lindif.2011.12.004

Akkan, S. N., & Horzum, T. (2024). Illuminating the landscape of mathematical resilience: A systematic review. *Journal of Pedagogical Research, 8*(1), 312-338. https://doi.org/10.33902/JPR.202420093

*Andersen, P., Weisstein, F. L., & Monroe, K. B. (2024). Math anxiety effects on consumer purchase decisions: The role of framing. *Marketing Letters*, *35*(2), 367–380. https://doi.org/10.1007/s11002-024-09732-8

Ashcraft, M. H. (2002). Math anxiety: Personal, educational, and cognitive consequences. *Current Directions in Psychological Science, 11*(5), 181-185. https://doi.org/10.1111/1467-8721.00196

Ashcraft, M. H. (2019). Models of math anxiety. In I. C. Mammarella, S. Caviola, & A. Dowker (Eds.), *Mathematics anxiety: What is known and what is still to be understood* (pp. 1–19). Routledge.

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). Psychology Press.

*Barroso, C., Ganley, C. M., McGraw, A. L., Geer, E. A., Hart, S. A., & Daucourt, M. C. (2021). A meta- analysis of the relation between math anxiety and math achievement. *Psychological Bulletin*, *147*(2), 134-168. https://doi.org/10.1037/bul0000307

Beilock, S. L., & Maloney, E. A. (2015). Math anxiety: A factor in math achievement not to be ignored. *Policy Insights From the Behavioral and Brain Sciences*, *2*(1), 4-12. https://doi.org/10.1177/2372732215601438

Bosmans, G., & Smedt, B. D. (2015). Insecure attachment is associated with math anxiety in middle childhood. *Frontiers in Psychology*, *6*, 1596. https://doi.org/10.3389/fpsyg.2015.01596

Caviola, S., Carey, E., Mammarella, I. C., & Szucs, D. (2017). Stress, time pressure, strategy selection and math anxiety in mathematics: A review of the literature. *Frontiers in Psychology*, *8*, 1488. https://doi.org/10.3389/fpsyg.2017.01488

Caviola, S., Mammarella, I. C., & Kovas, Y. (2019). Math anxiety in children with and without mathematical difficulties: The role of gender and genetic factors. In I. C. Mammarella, S. Caviola, & A. Dowker (Eds.), *Mathematics anxiety: What is known and what is still to be understood* (pp. 141-155). Routledge.

Caviola, S., Mammarella, I.C., Szűcs, D. (2022). Individual differences in mathematical abilities and competencies. In M. Danesi (Ed), *Handbook of Cognitive Mathematics* (pp. 1-32). Springer. https://doi.org/10.1007/978-3-030-44982-7_28-1

Caviola, S., Primi, C., Chiesi, F., & Mammarella, I. C. (2017). Psychometric properties of the Abbreviated Math Anxiety Scale (AMAS) in Italian primary school children. *Learning and Individual Differences, 55,* 174–182. https://doi.org/10.1016/j.lindif.2017.03.006

Caviola, S., Toffalini, E., Giofrè, D., Ruiz, J. M., Szűcs, D., & Mammarella, I. C. (2021). Math performance and academic anxiety forms, from sociodemographic to cognitive aspects: A meta-analysis on 906,311 participants. *Educational Psychology Review, 34*(1), 363-399. https://doi.org/10.1007/s10648-021-09618-5

Cipora, K., Artemenko, C., & Nuerk, H.-C. (2019). Different ways to measure math anxiety. In I. C. Mammarella, S. Caviola, & A. Dowker (Eds.), *Mathematics anxiety: What is known and what is still to be understood* (pp. 20-41). Routledge.

Cipora, K., Santos, F. H., Kucian, K., & Dowker, A. (2022). Mathematics anxiety - Where are we and where shall we go? *Annals of the New York Academy of Sciences*, *1513*(1), 10-20. https://doi.org/10.1111/nyas.14770

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

Donolato, E., Toffalini, E., Giofrè, D., Caviola, S., & Mammarella, I. C. (2020). Going beyond mathematics anxiety in primary and middle school students: The role of ego-resiliency in mathematics. *Mind, Brain, and Education, 14*(3), 255–266. https://doi.org/10.1111/mbe.12251

Dowker, A. (2019). Mathematics anxiety and performance. In I. C. Mammarella, S. Caviola, & A. Dowker (Eds.), *Mathematics anxiety: What is known and what is still to be understood* (pp. 62-76). Routledge.

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

Fan, X., Hambleton, R. K., & Zhang, M. (2019). Profiles of mathematics anxiety among 15-year-old students: A cross-cultural study using multi-group latent profile analysis. *Frontiers in Psychology*, *10*, 1217. https://doi.org/10.3389/fpsyg.2019.01217

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

Herts, J. B., Beilock, S. L., & Levine, S. C. (2019). The role of parents' and teachers' math anxiety in children's math learning and attitudes. In I. C. Mammarella, S. Caviola, & A. Dowker (Eds.), *Mathematics anxiety: What is known and what is still to be understood* (pp. 190–210). Routledge.

Hill, F., Mammarella, I. C., Devine, A., Caviola, S., Passolunghi, M. C., & Szűcs, D. (2016). Math anxiety in primary and secondary school students: Gender differences, developmental changes and anxiety specificity. *Learning and Individual Differences*, *48*, 45-53. https://doi.org/10.1016/j.lindif.2016.02.006 https://doi.org/10.1007/s11218-023-09760-8

*Ishak, N.H., Yusoff, N.F., & Madihie, A. (2020). Resilience in mathematics, academic resilience, or mathematical resilience?: An overview. *Universal Journal of Educational Research*, *8*(5A), 34-39. https://doi.org/10.13189/ujer.2020.081905

*Jackson, C. D., & Leffingwell, R. J. (1999). The role of instructors in creating math anxiety in students from kindergarten through college. *Mathematics Teacher*, *92*(7), 583-586. https://doi.org/10.5951/MT.92.7.0583

Johnston-Wilder, S., & Lee, C. (2010). Mathematical resilience. *Mathematics Teaching,* (218), 38-41.

Johnston-Wilder, S., Lee, C., & Mackrell, K. (2021). Addressing mathematics anxiety through developing resilience: Building on self-determination theory. *Creative Education*, *12*(9), 2098–2115. https://doi.org/10.4236/ce.2021.129161

Lee, C., & Johnston-Wilder, S. (2017). The construct of mathematical resilience. In U. X. Eligio (Ed.), *Understanding emotions in mathematical thinking and learning*, (pp. 269-291). Elsevier Academic Press. https://doi.org/10.1016/B978-0-12-802218-4.00010-8

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

Luttenberger, S., Wimmer, S., & Paechter, M. (2018). Spotlight on math anxiety. *Psychology Research and Behavior Management*, *11*, 311-322. https://doi.org/10.2147/PRBM.S141421

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

Maloney, E. A., & Beilock, S. L. (2012). Math anxiety: Who has it, why it develops, and how to guard against it. *Trends in Cognitive Sciences*, *16*(8), 404-406. https://doi.org/10.1016/j.tics.2012.06.008

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., Caviola, S., Rossi, S., Patron, E., & Palomba, D. (2023). Multidimensional components of (state) mathematics anxiety: Behavioral, cognitive, emotional, and psychophysiological consequences. *Annals of the New York Academy of Sciences*, *1523*(1), 91-103. https://doi.org/10.1111/nyas.14982

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

Morsanyi, K., Mammarella, I. C., Szücs, D., Tomasetto, C., Primi, C., & Maloney, E. A. (2016). Editorial: Mathematical and statistics anxiety: Educational, social, developmental and cognitive perspectives. *Frontiers in Psychology*, *7*, 1083. https://doi.org/10.3389/fpsyg.2016.01083

Orbach, L., Herzog, M., & Fritz, A. (2019). Relation of state- and trait-math anxiety to intelligence, math achievement and learning motivation. *Journal of Numerical Cognition*, *5*(3), 371-399. https://doi.org/10.5964/jnc.v5i3.204

*Organization for Economic Cooperation and Development. (2013). *PISA 2012 assessment and analytical framework: Mathematics, reading, science, problem solving and financial literacy*. OECD Publishing.

Organization for Economic Cooperation and Development. (2015). Does Math Make You Anxious?, *PISA in Focus* (No. 48). OECD Publishing.

Oszwa, U. (2022). Mathematical resilience as a conceptual framework for school practice. *Multidisciplinary Journal of School Education*, *11*(21), 99-114. https://doi.org/10.35765/mjse.2022.1121.05

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*, 42. https://doi.org/10.3389/fpsyg.2016.00042

Petronzi, D., Staples, P., Sheffield, D., & Hunt, T. (2019). Acquisition, development and maintenance of math anxiety in young children. In I. C. Mammarella, S. Caviola, & A. Dokwer (Eds.), *Mathematics anxiety. What is known and what is still to be understood* (pp. 77-102). Routledge.

*Radišić, J., Videnović, M., & Baucal, A. (2015). Math anxiety - Contributing school and individual level factors. *European Journal of Psychology of Education, 30*, 1-20. https://doi.org/10.1007/s10212-014-0224-7

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

*Ramirez, G., Chang, H., Maloney, E. A., Levine, S. C., & Beilock, S. L. (2016). On the relationship between math anxiety and math achievement in early elementary school: The role of problem-solving strategies. *Journal of Experimental Child Psychology*, *141*, 83–100. http://doi:10.1016/j. jecp.2015.07.014

*Ramirez, G., Gunderson, E. A., Levine, S. C., & Beilock, S. L. (2013). Math anxiety, working memory, and math achievement in early elementary school. *Journal of Cognition and Development*, *14*(2), 187-202. http://doi:10.1080/15248372.2012.664593

Ramirez, G., Shaw, S. T., & Maloney, E. A. (2018). Math anxiety: Past research, promising interventions, and a new interpretation framework. *Educational Psychologist*, *53*(3), 145-164. https://doi.org/10.1080/00461520.2018.1447384

*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

*Rolison, J. J., & Morsanyi, K. (2015). Can I count on getting better? Association between math anxiety and poorer understanding of medical risk reductions. *Medical Decision Making*, *36*(7), 876-886. https://doi.org/10.1177/0272989X15602000

*Rubinsten, O., Levy, H. E., & Cohen, L. D. (2019). Probing the nature of deficits in math anxiety: Drawing connections between attention and numerical cognition. In I. C. Mammarella, S. Caviola, & A. Dowker (Eds.), *Mathematics anxiety: What is known and what is still to be understood* (pp. 156-177). Routledge.

Rubinsten, O., Marciano, H., Eidlin Levy, H., & Daches Cohen, L. (2018). A framework for studying the heterogeneity of risk factors in math anxiety. *Frontiers in Behavioral Neuroscience*, *12*, 291. https://doi.org/10.3389/fnbeh.2018.00291

Sawka-Miller, K.D. (2011). Test anxiety. In S. Goldstein & J. A. Naglieri (Eds), *Encyclopedia of Child Behavior and Development* (pp. 1478-1479). Springer. https://doi.org/10.1007/978-0-387-79061-9_2890

Szűcs, D., & Mammarella, I. C. (2020). Mathematics anxiety. *Educational Practices Series No. 31*. UNESCO International Bureau of Education. https://unesdoc.unesco.org/ark:/48223/pf0000373402

Szucs, D., & Mammarella, I. C. (2024). A biopsychological–social view of mathematical development. *Current Opinion in Behavioral Sciences*, *55*, 101332. https://doi.org/10.1016/j.cobeha.2023.101332

*Thomas, G., & Dowker, A. (2000, September). *Mathematics anxiety and related factors in young children* [Paper presentation]. British Psychological Society, Developmental Section Conference 2000, Bristol, U K.

Tomasetto, C. (2019). Gender stereotypes, anxiety, and math outcomes in adults and children. In I. C. Mammarella, S. Caviola, & A. Dokwer (Eds.), *Mathematics* *anxiety. What is known and what is still to be understood* (pp. 77-102). Routledge.

*Trigueros, R., Aguilar-Parra, J. M., Mercader, I., Fernández-Campoy, J. M., & Carrión, J. (2020). Set the controls for the heart of the maths. The protective factor of resilience in the face of mathematical anxiety. *Mathematics*, *8*(10), 1660. https://doi.org/10.3390/math8101660

Vanbinst, K., Bellon, E., & Dowker, A. (2020). Mathematics anxiety: An intergenerational approach. *Frontiers in Psychology*, *11*, 1648. https://doi.org/10.3389/fpsyg.2020.01648

Wang, Z., Hart, S. A., Kovas, Y., Lukowski, S., Soden, B., Thompson, L. A., Plomin, R., McLoughlin, G., Bartlett, C. W., Lyons, I. M., & 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., Mazzocco, M. M., Plomin, R., & 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

*Wang, Z., Oh, W., Malanchini, M., & Borriello, G. A. (2020). The developmental trajectories of mathematics anxiety: Cognitive, personality, and environmental correlates. *Contemporary Educational Psychology*, *61*(4), 101876. https://doi.org/10.1016/j.cedpsych.2020.101876

World Health Organization. (2022, June 8). Mental disorders. World Health Organization. https://www.who.int/news-room/fact-sheets/detail/mental-disorders (accessed September 2024)

*Wu, S. S., Barth, M., Amin, H., Malcarne, V., & Menon, V. (2012). Math anxiety in second and third graders and its relation to mathematical achievement. *Frontiers in Psychology*, *3*, 162. https://doi.org/10.3389/fpsyg.2012.00162

Xenofontos, C., & Mouroutsou, S. (2023). Resilience in mathematics education research: A systematic review of empirical studies. *Scandinavian Journal of Educational Research*, *67*(7), 1041-1055. https://doi.org/10.1080/00313831.2022.2115132

Živković, M., Pellizzoni, S., Doz, E., Cuder, A., Mammarella, I., & Passolunghi, M. C. (2023). Math self-efficacy or anxiety? The role of emotional and motivational contribution in math performance. *Social Psychology of Education: An International Journal*, *26*, 579-601. https://doi.org/10.1007/s11218-023-09760-8