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INFLUENCE OF COGNITIVE, EMOTIONAL, COGNITIVE-MOTIVATIONAL, AND SOCIAL FACTORS ON MATH PERFORMANCE IN PRIMARY AND MIDDLE SCHOOL STUDENTS

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ABSTRACT

Mathematics builds on several cognitive abilities (Passolunghi et al., 2008; Krajewski & Schneider, 2009; Geary, 2011) implemented by an extensive neural network in the brain (Goswami & Szűcs, 2011; Fias et al., 2013), and influenced by emotional aspects: feelings of apprehension, tension, worry, enjoyment, hope, pride (Passolunghi et al., 2019; Krizinger et al., 2009; Goetz & Hall, 2013), cognitive-motivational (self-efficacy and self-esteem), and social aspects (i.e., cultural norms).

The present dissertation aims to consider the joint role of cognitive (working memory, inhibition, shifting), emotional (general anxiety, math anxiety, and enjoyment in maths), motivational (math self-efficacy and self-concept), and social factors (explicit math gender stereotypes) in mathematical performance in typically developing children between 8 and 13 years old. The relation among these different factors was addressed in four related studies. The studies present in this dissertation enrich the literature with a new explanation of the relation between math anxiety and executive functions in middle school students (Study 1), the relation between math anxiety, self-competence, verbal and visuospatial working memory in 3rd, 5th, and 7th-grade students (Study 2), the important relationship between math anxiety, math gender stereotypes and arithmetic reasoning in primary school children (Study 3), and important relationship between positive, negative emotions, math self-efficacy, and math performance in fifth-grade students (Study 4). Studies will be presented with a theoretical background and empirical evidence, methodology, statistical analyses, and results. In the general discussion will be presented the main findings of the four studies with educational implications.

ABSTRACT (Italian version)

La matematica si basa su diverse abilità cognitive (Passolunghi et al., 2008; Krajewski & Schneider, 2009; Geary, 2011) implementate da una vasta rete neurale nel cervello (Goswami & Szǜcs, 2011; Fias et al, 2013), e influenzato da aspetti emotivi: sentimenti di apprensione, antipatia, tensione, preoccupazione, godimento, speranza, orgoglio (Passolunghi et al., 2019; Krizinger et al., 2009; Goetz & Hall, 2013), cognitivo-motivazionali (autoefficacia e autostima), e sociali (es. norme culturali).

La presente dissertazione mira a considerare il ruolo congiunto di fattori cognitivi (memoria di lavoro, inibizione, shifting), emotivi (ansia generale, ansia per la matematica e divertimento in matematica), motivazionali (autoefficacia matematica e concetto di sé) e sociali (stereotipi espliciti di genere in matematica) nelle prestazioni matematiche in bambini con sviluppo tipico tra gli 8 e i 13 anni. La relazione tra questi diversi fattori è stata affrontata in quattro studi. Gli studi presenti in questa dissertazione arricchiscono la letteratura con una nuova spiegazione della relazione tra ansia matematica e funzioni esecutive in studenti di scuola media (Studio 1), la relazione tra ansia per la matematica, auto competenza, memoria di lavoro verbale e visuospaziale in studenti di 3°, 5°, e 7° grado (Studio 2), l'importante relazione tra ansia per la matematica, stereotipi di genere in matematica e ragionamento aritmetico nei bambini della scuola primaria (Studio 3), e l'importante relazione tra emozioni positive e negative, autoefficacia matematica e performance matematica negli studenti di quinta elementare (Studio 4). Gli studi saranno presentati con uno sfondo teorico e prove empiriche, metodologia, analisi statistiche e risultati. Nella discussione generale saranno presentati i principali risultati dei quattro studi con implicazioni educative.

CONTENTS

GENERAL INTRODUCTION

Why mathematics is important?

Mathematics represents a set of heterogeneous and multidimensional disciplines crucial for life (Rugani et al., 2010; Bull et al., 2008). For example, science, technology, engineering, personal wellbeing (Reyna et al., 2009), day-to-day living, participation in a social community (Dougherty, 2003; Mazzocco, 2008) all require mathematics. It's a disciple that builds several cognitive abilities (Passolunghi et al., 2008; Krajewski & Schneider, 2009; Geary, 2011) implemented by an extensive neural network in the brain (Goswami & Szǜcs, 2011; Fias et al., 2013). This cognitive network is influenced by emotional aspects: like apprehension, tension, worry, enjoyment, hope, pride (Passolunghi et al., 2019; Krizinger et al., 2009; Goetz & Hall, 2013), as well as self-efficacy/self-esteem, and cultural norms.

Bronfenbrenner (1979) developed the bioecological theory that labelled aspects or levels of the environment that influence children's development, including the microsystem (family, peers, school), the mesosystem (interaction of extended levels of microsystem), the exosystem (media, services, neighbours), and the macrosystem (society, culture). Using Bronfenbrenner's model, we will demonstrate how complex and multidimensional math learning could be (ranging from the national to the parental influence). It is relevant to have a clear picture of the acquisition of math abilities and evaluate which factors promote or hinder this learning process.

Both national and international assay monitors these aspects. The Organisation for Economic Co-operation and Development (OECD) developed the survey for the Programme for the International Student Assessment (PISA) that investigates the reading, mathematics, and science skills levels of over half a million 15-year-olds from seventy-nine different countries and economies, including Italy. OECD PISA is the largest international survey in the field of education. The focus of the program is not on the mastery of curricular content, which is assessed by individual school systems and is difficult to compare; rather, it is on the ability to cope with and solve problems in everyday life and on how to continue learning in the future.

The PISA survey consists mainly of multiple-choice questions. It includes open-ended questions, which make up about a third of the test. Students are asked to answer a background questionnaire, providing information about themselves and their attitude towards learning. As well, school leaders receive a questionnaire about their schools to complement the information provided by the students. Participating countries may also choose to administer other optional PISA questionnaires: on computer familiarity, educational background, and parents' cultural background. The survey has been held every three years since 2000. In 2018, the Italian sample of students was stratified by geographical area and type of education, including vocational training centers and secondary schools. 11,785 Italian 15-year-old students participated in the PISA test, divided into 550 total schools. The results showed that a growing number of students struggle with numbers and mathematical calculations. The data from 2018 showed that 23% of students in OECD countries, and 32% of students in all participating countries did not reach the baseline of Level 2 (extract relevant information from a single source, or use basic algorithms, formulae, procedures, and conventions to solve problems involving whole numbers). The 25% of Italian students did not reach the baseline of Level 2 in maths in 2018. They performed poorly when asked to formulate mathematical calculations, although they produced better results when applying and evaluating math outcomes. Difficulties in mathematics are often associated with strong psychological discomfort in the form of anxiety or tension. These feelings have important emotional, cognitive, and social implications.

In Italy, the National Institute for the Evaluation of the Education and Training System (INVALSI) is responsible for administering tests and collecting data, that are then compared with results of other countries. The INVALSI measures some of the basic skills in mathematics set out in the national indications and guidelines in four areas: data and predictions, numbers, space and figures, relationships, and functions. The questions vary in complexity according to the grade level examined. They often start with problems relating to the real world and test the most relevant disciplinary knowledge (i.e. problem-solving and ability to argue a specific result). The assessments in primary school (Grade 2 and Grade 5) are equal for everyone and done on paper-and-pencil. In middle and secondary school (Grade 8, Grade 10, and Grade 13), assessments are computer-based in several forms of equivalent difficulty. In the 2019 INVALSI reported that there were no substantial differences in primary schools in macro-areas. Only in the South and the two large islands, Grade 5 showed a negative difference of approximately 9 points compared to the national average. It should be noted that primary schools in the central part of Italy (Umbria and Marche) and the south (Basilicata and Molise) obtained the best results. As of middle school, a significant diversity becomes in the results from the North and the South (and the islands). The central parts of the country (gradually) lose ground in middle school compared to the two macro-areas of the North, achieving results that are no different from the Italian average. Giofrè and colleagues (2020) using the INVALSI data set with Grade 2, 5, and 8 (period from 2010 to 2018) showed that boys out-performed girls in mathematics, and girls out-performed boys in reading, from the 2nd through to the 8th grade. The northern part of Italy is characterized by greater gender equality and the results showed that the gender gap in mathematics was larger in the richer northern regions than in southern regions.

Mathematics and factors that promote math performance

Given this specific national and international situation, literature has extensively evaluated which factors promote or hinder math performance. Below is a detailed analysis of the individual factors fundamental for success in math. These aspects can be grouped into the following categories as cognitive, emotional, cognitive-motivational, and social factors that influence math performance.

Influence of cognitive factors on mathematics performance

Cognitive factors are the foundation for performance and learning; these factors (modulate performance that may improve or decline,) involve cognitive functions like attention, memory, and reasoning (Danili & Reid, 2006; Passolunghi et al., 2007). They include, also, intelligence (Deary et al., 2007) and processing speed (Fuchs et al., 2006). In this dissertation, we will specifically consider Executive Functions (EFs), such as working memory (WM), inhibition, and shifting.

EFs are defined as a set of interconnected mental processes crucial to 1) hold, update and actively manipulate information, 2) inhibit inappropriate responses, 3) show flexibility in strategies, ideas, and activities (Miyake & Friedman, 2012; Miyake & Shah, 1999; Zelazo & Müller, 2002). These cognitive functions have developmental trajectories, with rapid changes during the preschool years (Best & Miller, 2010; Garon et al., 2008; Zelazo et al., 2016). EFs have been extensively investigated in children (Garon et al., 2008), resulting strongly related to learning abilities (on school achievement) and math performance (Bull & Scerif, 2001; Clark et al., 2010; Mulder & Cragg, 2014). Research has indicated that WM, inhibition, and shifting are factors that play a central role in the development of math skills (Passolunghi & Siegel, 2004; Friso-van den Bos et al., 2013; Usai et al., 2014; Cragg et al., 2017). Geary (1993) demonstrated the relationship between poor EFs and the procedure of calculation. He suggested that math difficulties present after second grade would increase math disability (later in life). Poor EFs influence the organization of math problems and the ability to apply strategies for successful math problem resolution (Mazzocco & Myers, 2003). Usai and colleagues (2018) longitudinally investigated EF profiles in 5-year-old children and their later math achievement. The study showed that children with weak WM-shifting profiles (performed (equally) with typical EF profile group using Grade 1 arithmetic and math problem tasks) displayed difficulties in Grade 3 EF deficit children.

Working memory and math performance

WM presents an ability to temporarily store, manipulate, and control incoming information (Baddeley, 2000) or a unitary system that is primarily involved in attentional control (Engel et al., 1999). The well-known WM model is a tripartite model which includes a central executive, responsible for data storage, processing, and monitoring, and another two domain-specific systems devoted to processing either verbal or visuospatial information (Baddeley & Hitch, 1974). The episodic buffer was added as the fourth element of the model and presents the limited capacity system that provides and integrates temporary storage of information from long-term memory and two subsystems (Baddeley, 2000). According to Engel and colleagues (1999), WM reflects the capacity of the central executive that includes inhibition of irrelevant information, task switching, information updating, goal management, and strategic retrieval from long-term memory. From this perspective, WM capacity during complex cognitive tasks engages more the ability to control and allocate attention to the amount of information that can be stored. This model connects greater WM capacity with greater attentional control.

Research has revealed that children who poorly perform in WM tasks do not reach expected levels of math competencies (Gathercole & Pickering, 2000; Passolunghi & Siegel, 2001; Passolunghi & Mammarella, 2010, 2012; Bizzaro et al., 2018). WM is one of the cognitive functions involved in performing arithmetic operations, especially in mental calculation (Mazzocco & Kover, 2007; Passolunghi & Siegel, 2001, 2004). A direct link has been revealed between WM abilities and math performance (Gathercole & Pickering, 2000; Passolunghi & Siegel, 2001). For Gathercole and Pickering (2000), seven-year-old children who scored highly in math performance displayed better results in WM tasks. In the sample of fourteen-year-old children, WM tasks were strongly correlated with math and science achievement. To give the crucial role of WM in the learning process, it is fundamental to enter more specifically in the complex interplay with other EFs factors.

Also, studies have focused on verbal and visuospatial WM. Kane and colleagues (2004) indicated a substantial correlation between verbal and visuospatial domains, while Swanson (2008) observed this distinction in some ages, but not in others. Some of the studies showed that verbal WM is more likely to be related to reading attainment while visuospatial WM is more related to maths performance (Giofrè et al., 2018). Soltanlou and colleagues (2015) showed a developmental perspective in this connection: verbal WM was the best predictor of multiplication performance in 3rd-grade students while visuospatial WM was the best predictor of maths performance in the 4th grade. The previously mentioned literature indicates that it is fundamental to investigate the specific influence of these two types of WM according to the age and the type of task involved (Giofrè et al., 2018).

Inhibition and math performance

Fewer studies investigated the relationship between inhibition and math performance, and a majority of studies report that inhibitory control predicts math performance (Bull & Scerif, 2001; Campos et al., 2013). The relationship between inhibition and mathematical performance in preschool and school children has emerged in some studies (Szücs et al., 2013; Usai et al., 2018). Passolunghi and Siegel (2001) exhibited the importance of inhibition in solving word problems when selecting data from a set that also contains irrelevant information. St Clair-Thompson and Gathercole (2006) tested a sample of middle-school students and found an important WM role in learning and inhibition. EFs showed an independent influence on learning achievement in mathematics, English, and science, supporting previous studies (Bull & Scerif, 2001; Jarvis & Gathercole, 2003). Bull and Scerif (2001) reported that the primary difficulty for primary-school children lies in inhibiting a strategy previously learned and later switched to a new one. A meta-analysis that investigated the strength of the relationship between EF components (visuospatial and verbal updating, inhibition, shifting, visuospatial sketchpad, and phonological loop) showed a lower correlation with visuospatial and verbal updating (compare to other components). For the inhibition component, the type of mathematical measurement was important: with composite measures, the correlation was higher compared to arithmetic tests (Friso-van den Bos et al., 2013).

Shifting and math performance

Shifting, as one of the EFs, guides the ability to switch between tasks or strategies and it is less studied compared to the research regarding WM and math performance (Bull & Scerif, 2001). Yeniad and colleagues (2013) revealed an association between shifting and math performance. When observing children with a higher capacity of shifting, they found better results in math performance, providing a precise structure for the categorization of shifting tasks by levels of complexity. In this meta-analysis, shifting appears to predict math and reading across all developmental stages. There are studies in which individuals need to switch from one task to another, to change the focus of their attention from left to right, for example, or to choose between two types of categorization (e.g., high/low vs odd/even). Cragg and Nation (2009) conducted two experiments with children of different ages. They showed that younger children (5-8 years old) had greater difficulty inhibiting unrelated information than the older ones (9-11 years old). The variety of tasks used to measure shifting and the different scoring methods involved (reaction time, accuracy, efficiency, or combined scores) can be seen as a problem in the interpretation of the previous results. The shifting rule was implicit in some studies and explicit in others.

Previously mentioned studies confirmed a well-known effect of cognitive factors in shaping math performance, but also underlined the necessity for more research to investigate the influence of inhibition and shifting separately from WM components regarding math performance. Not only cognitive components influence math performance, emotional and cognitive-motivational components are also important.

Influence of emotional factors on mathematics performance

Emotional factors present feelings associated with performance and can be defined in the terms of three independent, bipolar dimensions: arousal-no arousal, pleasure-displeasure, dominance-submissiveness. In the last twenty years, we have seen an increase in the number of studies that investigate achievement emotions in primary, middle, and high school students (Pekrun, 2000; Pekrun et al., 2006; Frenzel et al., 2007; Goetz et al., 2007). Some have shown that emotions play a fundamental role in learning and memory, motivation, development, psychological health across all age groups, genders, and cultures. It is clear the impact of emotions in an educational context is important (Lewis & Haviland-Jones, 2000; Shweder & Haidt, 2004; Pekrun et al., 2006), Ashby and colleagues (1999) showed that changing brain dopamine levels affecting long-term memory can influence students' achievement. The study of Pekrun and colleagues (2002) demonstrated that emotions influence the process of learning and performance by facilitating students' self-regulation. Emotional factors that influence math performance can be split into two areas: positive, such as enjoyment in math (Pekrun et al., 2002), and negative, such as math anxiety (Passolunghi et al., 2019).

Positive emotion (enjoyment in math) can effectively contribute to self-regulation, motivation, and activation of cognitive processes (Pekrun et al., 2002). Based on the control-value theory of achievement of emotions (Pekrun, 2000) various studies analysed the relationship between perceived classroom environments and emotions in math (enjoyment, anxiety, boredom, and anger). A cross-cultural study (Italy, Germany, and the USA) investigating the influence of enjoyment, boredom, and anxiety regarding math and native language development in second-and fourth-grade students showed a negative relationship between anxiety and achievement. A positive relationship was revealed only between enjoyment and math, and not between enjoyment and language development (Raccanello et al., 2018). The younger students showed more enjoyment and less anxiety and boredom. The results confirmed the complex role of both positive (enjoyment) and negative emotions (anxiety) regarding achievement.

Lewis (1970) defined anxiety as a "dispositional and dysfunctional response to a situation perceived as threatening". 10% of the children in a school environment manifest anxiety, starting from kindergarten (Egger & Angold, 2006). Even if the detrimental effect of anxiety is acknowledged in children, its role in school performance is underestimated if compared with that held by the cognitive abilities (Alloway & Passolunghi, 2011; St Clair-Thompson & Gathercole, 2006). The assessment of general anxiety (GA) is a critical issue in young children. The complexity of its construct and the consequential self-evaluation has not been reported with high reliability. The assessment of anxiety provided by the teachers has resulted to be a reliable measure of the children's emotional state (e.g., Lyneham et al., 2008; Salbach-Andrae et al., 2009) and a predictor of their math achievement (e.g., Cargnelutti et al., 2017). Teachers' ratings can be considered a valid indicator of the students' anxiety condition.

Ashcraft (2002) defines math anxiety (MA) as " a feeling of tension, apprehension, or fear that interferes with math performance" and explained that individuals with high MA avoid situations in which they need to perform mathematical calculations. Avoiding can cause less competency, less exposure, and less mathematics practice, leaving students more anxious and mathematically unprepared. Research has underlined a negative influence of MA regarding mathematical performance. Children and adults with high MA showed worse results in mathematics and a lower quality of math learning (Ashcraft, 2002; Vukovic et al., 2013; Cargnelutti et al., 2017; Ramirez et al., 2016; Dowker et al., 2016).

Five meta-analyses have examined the relationship between MA and math ability. In chronological order, the first attempt to meta-analyze the literature was made by Hembree (1990), followed nine years later by Ma (1999). These works included several studies on secondary-school students, almost ignoring younger children. The two most recent meta-analyses, conducted by Namkung and colleagues (2019), and Zhang and colleagues (2019), include a larger number of studies involving primary-school children. They underscore a significant negative correlation between MA and math performance ($r = -.34$ and $r = -.32$, respectively), confirming the findings emerging from the two earlier meta-analyses. The last meta-analyses (Barroso et al., 2020) compared with the previous two studies includes adult sample, unpublished data, and conduct authors queries for missing data that led them to have many more effect sizes. The results, in general, were very similar and their overall correlation was $r = -.28$. The fundamental aspect that came to light was that cognitive and emotional problems underlying math difficulties could be considered largely dissociable (Devine et al., 2018).

Positive and negative emotions are not the only factors that influence math performance together with cognitive ones.

The influence of cognitive-motivational factor on math performance

Bandura (1986) defined the cognitive component of motivation as a “capacity to exercise self-influence by personal challenge and reaction to one’s own attainments”. When we use the term cognitive-motivational factors we mainly think about self-efficacy that

Bandura (1977) defined as “belief in one’s ability to succeed in achieving an outcome or reaching a goal”. Belief in one’s abilities is strongly correlated with successful learning and can influence personal development and well-being (Marsh & O’Mara, 2008). Students with positive beliefs about their mathematical knowledge will be highly engaged in math activities. Students with negative beliefs about math will avoid math activities, which means less math practice and higher MA (Mullis et al., 2012; Ramirez et al, 2013; Dowker et al., 2012). The importance lies in the development of positive beliefs towards math which will lead to higher confidence towards math in students. Pajares and Miller (1994) reported that mathematical performance was reinforced by beliefs of self-efficacy. More recently it has been shown that students who approach school with strong internal resources (such as self-efficacy) manage to engage more in mathematical learning and are better "equipped" to meet the challenges of the discipline (Martin & Rimm-Kaufman, 2015). Longitudinal studies with middle and high school students have shown self-concept and self-efficacy as important mediators of academic achievement (Skaalvik & Skaalvik, 2006). Students who self-rated themselves higher performed better in math. These are some of the results that confirmed the clear relationship between positive math beliefs and math performance in a way that students who believe more in their capacity to solve math problems are better at performing math. Students with low levels of self-esteem and negative opinions of their mathematical abilities are at high risk to perform math poorly. The important step when faced with low math performance is the development of positive attitudes towards math which will lead to higher confidence towards math in all students.

Influence of social factors on mathematics performance

Gender stereotypes present the beliefs that we have about male and female characteristics. These vary based on culture, time frame, and existing stereotypes; they are often related to the roles that men and women play in society (Martin & Dinella, 2002).

“Math is for boys” presents a common cultural stereotype worldwide. Different studies on different ages showed that math stereotypically presents a male domain (Cvencek et al., 2011). Research has investigated the gender differences in math and showed gender gaps in different cultures that were correlated with gender equality (Kiefer & Sekaquaptewa, 2007; Guiso et al., 2008; Tomasetto et al., 2011). One of the possible explanations for this kind of gender gap Tomasetto and colleagues (2011) found in stereotype threat with the sample of girls from kindergarten to the second grade. The study showed a moderating role from the mother and only in a sample of girls whose mothers still had the belief that boys were better at math. An international comparison of student achievement (OECD,2018) showed the gender gap in math. In the Italian sample, boys outperformed girls by 16 points (average across countries was 5 score points higher for boys). The results showed that girls, even when they performed as well as boys, showed less self-belief in their capacity for math learning, less openness to solve problems, less motivation for math learning, and less persistence. In the sample of high-performing students in Italy, four boys expected to work as an engineer before the age of 30, while one in eight girls expected the same. An insignificant percent of girls expected to work in ICT professions compared to 7% of the boys. The results also showed that gender differences exist in the experience of the fear of failure. Girls reported more frequently and to a larger extent than boys.

To get a complete framework of the variables involved in the lower math performance of girls compared to boys, the incidence of emotional, cognitive-motivational, and social factors, such as general anxiety, MA, enjoyment in math, self-competence, self-efficacy, and math gender stereotypes should be considered. We need more longitudinal studies with younger children that will investigate the influence of cognitive, emotional, and cognitive-motivational factors on math performance because these results can give a clearer picture of the type of interventions need to improve math skills in primary and middle school students.

Aim and structure of the dissertation

Given the scarcity of literature that jointly investigates the influence of cognitive, emotional, cognitive-motivational, and social components in primary and middle-school students and math achievement, my main aim is to examine the relationship between all above components and their influence on math performance in students from 8 to 13 years old. The studies presented will enrich the discussion regarding the following topics: 1. the relationship between MA and EFs in middle school students (Study 1); 2. the relationship between MA, self-competence, verbal (VWM), and visuospatial (VSWM) WM in 3^{rd}, 5^{th}, and 7^{th}-grade students (Study 2); 3. the important relationship between MA, math gender stereotypes and arithmetic reasoning in primary school children (Study 3); and 4. the important relationship between positive, negative emotions, math self-efficacy, and math performance in fifth-grade students (Study 4).

In Study 1, we investigated the influence of EFs (VWM, VSWM, Inhibition, and Shifting) and MA on math performance in middle school students. We tried to reach the following aims: 1) to better examine the relationship between MA and math performances; 2) to further examine the relationship between EFs and math performance, often left unexplored during the middle school period; and 3) to investigate, for the first time, the interplay between EFs (VWM, VSWM, inhibition, and shifting) and MA on math performances. To achieve our aims, we hypothesized that: a) MA would have a significant and negative relationship with math performance referring specifically to middle school students, b) different EFs (e.g. VWM, VSWM, inhibition, and shifting) would correlate positively with math performance, c) the relation between MA and math performance will be mediated through cognitive factors (VWM, VSWM, inhibition, and shifting) in middle school students.

Study 2 investigated the influence of cognitive (VWM and VSWM), emotional (MA), and cognitive-motivational factors (self-competence) on arithmetic reasoning in 3^{rd}, 5^{th}, and

7th-grade students. We focused on both the interplay between these factors and their influence on arithmetic reasoning trying to reach the following aims: 1. Investigating the correlations between WM components (verbal and visuospatial), MA, self-competence, and arithmetic reasoning, 2. Determining whether VWM and VSWM and self-competence, have a direct or indirect effect in the relationship between MA and arithmetic reasoning, in order to better analyse the underlying mechanism at the base of the relation between MA and maths achievement, extending and completing recent study in the field (Justicia-Galiano et al., 2017; Soultanlou et al., 2015), 3. Examining the specific interplay between VWM, VSWM, and self-competence, not fully investigated in previous studies (Justicia-Galiano et al., 2017).

In Study 3 we focused on the relationship between MA, explicit math gender stereotypes, and arithmetic reasoning in the sample of primary school children (3rd, 4th, and 5th-grade). Also, we investigated gender differences in cognitive (VWM and VSWM), emotional (MA), and social factors (math gender stereotypes). The aims were to 1. observe jointly the relation between MA, explicit math gender stereotypes, and arithmetic reasoning; 2. investigate the gender differences in MA, explicit math gender stereotypes, and arithmetic reasoning. We hypothesized that exist: a) a significant relationship between MA, explicit math gender stereotypes, and arithmetic reasoning in students of 3rd, 4th, and 5th grade, and; b) a significant gender differences in MA and explicit math gender stereotypes in primary school students (3rd, 4th, and 5th grade).

Study 4 investigated the influence of positive and negative emotions (GA, MA, enjoyment), and cognitive-motivational factors (self-efficacy) on math performance in fifth-grade students. The aims of the study were 1. to better understand the relationship between positive and negative emotions in the fifth-grade students; 2. and to observe how GA, MA, enjoyment in math, and math self-efficacy predict math performance in the fifth-grade students. We hypothesized that MA will positively correlate with GA and negatively with math self-efficacy, enjoyment, and math achievement and that math enjoyment will positively correlate with self-efficacy, and math attainment but negatively with MA and GA. We were hypothesized that MA, independently from GA, can predict math performance. Also, we hypothesized the influence of MA, math self-efficacy, and enjoyment in math on math performance in fifth graders. The results showed a significant and negative relationship between MA, enjoyment, math self-efficacy, and math performance.

As the previous results showed, the influence of cognitive, emotional, cognitive-motivational, and social factors on math performance in primary and middle school students in the third year of a project, we proposed the training (as an intervention) for the improvement of math performance in 5th grade students. The three training were developed as follows: two as experimental, one to reduce MA through techniques and exercises, and one concentrated on the practice of math calculation (addition, subtraction, multiplication, and division) through group exercises that were very playful and competitive. One training group was the control group and was based on emotional recognition and the importance of emotions in everyday life. It was not possible to finish all three trainings because of the world COVID- 19 pandemic. Only one training, for the reduction of MA, was finished and some of the results will be presented at the end of the thesis.

In Table 1 all four studies will be present with the number of participants, measures, aims, and hypotheses.

Chapter 1 will present Study 1 with a review of the influence of EFs and MA on math performance in middle school students. Some of the previous studies that investigated this relationship will be discussed. As well, the aims and hypothesis of the study and results will be exhibited.

Chapter 2 will present Study 2 with the review of the literature about the influence of cognitive, emotional, and motivational factors on arithmetic reasoning in 3^{rd}, 5^{th}, and 7^{th}-grade students along with the aims, hypothesis, and results.

Chapter 3 will discuss the gender differences and influence of MA and explicit math gender stereotypes on arithmetic reasoning in primary school children (3^{rd}, 4^{th}, and 5^{th}-grader) with the present literature and the aims, hypothesis, and results of Study 3.

Chapter 4 will present Study 4 with an introduction about emotional and cognitive-motivational factors that influence math performance in 5^{th} graders as well as aims, hypothesis, and results of the study.

Chapter 5 will present one of the trainings that we finished before the world COVID-19 pandemic and the initial provisional results.

In the final chapter, principal findings of all four studies are summarized with limits, strengths, and suggestions for future studies. There is also a discussion of educational implications of current studies.

STUDY	SAMPLE	MEASURES	AIMS	HYPOTHESIS
1	N = 105 middle school students (48 males and 57 females) M_{age} = 12.623	Verbal working memory Visuospatial working memory Inhibition Shifting Math Anxiety Math performance	1) to better evaluate the influence of MA on math calculation in middle school students; 2) to understand more closely the importance of EFs in mathematical performance; 3) to investigate the reciprocal role of cognitive (VWM, VSWM, inhibition, and Shifting) and emotional factor (MA) in mathematical performance in middle school students.	1.MA has a significant, direct, and negative effect on calculation skills; 2.cognitive factors (VWM, VSWM, inhibition, and shifting) have a significant, direct, and positive effect on mathematical performance; 3. an indirect effect of MA exists from cognitive factors on mathematical performance.
2	N = 335 students 3rd (123), 5th (109), 7th grade (103) 168 males and 167 females M_{age} = 10.54	Verbal working memory Visuospatial working Math anxiety Self-competence Arithmetic reasoning	1) to investigate the correlations between VWM, VSWM, MA, self-competence, and arithmetic reasoning; 2) to determine whether VWM, VSWM, and self-competence, have a direct or indirect effect in the relationship between MA and arithmetic reasoning, 3) to better analyse the underlying mechanism at the base of the relation between MA and maths achievement, extending and completing recent study in the field; 3) to examine the specific interplay between VWM, VSWM, and self-competence, not fully investigated in previous studies	1. VSWM, not VWM, has a more salient role in the interplay between MA and maths achievement, being particularly impaired by anxiety; 2. We expect the direct influence of VWM, VSWM, MA, and self-competence on arithmetic reasoning. We also expect an indirect influence of MA on arithmetic reasoning through the measures of VWM, VSWM, and self-competence; 3. the more a child has a positive self-competence, the higher the score on VWM will be.
3	N = 376 students 3rd (172) and 5th (148) grade 212 males and 186 females M_{age} = 9.61	Verbal working memory Visuospatial working memory Explicit math gender stereotypes Math Anxiety Arithmetic reasoning	1) observe jointly the relationship between MA, explicit math gender stereotypes, and arithmetic reasoning; 2) investigate the gender differences in VWM, VSWM, MA, explicit math gender stereotypes, and arithmetic reasoning.	1. there is a significant relationship between MA, explicit math gender stereotypes and arithmetic reasoning and; 2. a significant gender differences in MA and explicit math gender stereotypes students of 3rd, 4th, and 5th grade
4	N = 145 students 84 males and 61 females M_{age} = 10.36	Math anxiety General anxiety Math self-efficacy Enjoyment in math Math Performance	1) to better understand the relationship between positive and negative emotions in fifth-grade students; 2) and to better understand the influence of negative emotions (such as GA and MA), positive emotions (such as enjoyment in math) and self-efficacy, on math performance in fifth-grade students.	1. significant and negative relation between MA, positive emotions (enjoyment and math self-efficacy) and math performance, and 2. negative influence of MA on math performance, but a positive influence of math self-efficacy and enjoyment in math on math performance in the fifth-grade students.

Table 1. *Description of the studies*

CHAPTER 1

Executive functions, math anxiety, and math performance in middle-school students[1]

Given the relevance of math skills at both individual and social levels, knowing which factors are crucial to the mathematical acquisition, and possibly gaining a better understanding of how they interact, is a salient topic for our society. The literature indicates that domain-general precursors like intelligence (Giofrè, Mammarella, & Cornoldi, 2014;), executive functions (EFs) (Passolunghi & Siegel, 2001; 2004), and emotional factors Ashcraft & Kirk, 2001) modulate math achievement. For decades cognitive factors were studied separately from emotional factors. In the last twenty years, researchers have tried to propose a convergent model of the complex interplay between cognitive and emotional factors behind math acquisition (Ashcraft & Kirk, 2001; Ramirez Gunderson, Levin, & Beilock, 2013). These studies have mainly investigated working memory (WM) and math anxiety (MA) but leaving almost unexplored other aspects of executive functions (EFs) such as inhibition and shifting.

Furthermore, studies have been extensively studied in primary-school children (Mammarella, Hill, Devine, Caviola, & Szűcs, 2015), or adults (Ashcraft & Kirk, 2001) middle school students are greatly understudied. Studies showed a decline in motivation and performance for many students as they move from primary to the middle school environment (Eccles & Midgley, 1989) and literature showed that the academic developmental needs of middle school students are different from those of elementary and high school students (Eccles, Wigfield, Harold, & Blumenfeld., 1993).

To fill this gap the aims of our study are 1) to better examine the relationship between MA and maths performance; 2) to better examine the relationship between EFs and math

[1] Živković, M., Mammarella, I.C., Pellizzoni, S., & Passolunghi, M.C. (**submitted**). Executive functions, math anxiety and math performance in middle school students

performance; and 3) to investigate the interplay between EFs (VWM, VSWM, inhibition, and shifting) and MA on math performances.

1.1.Executive functions and mathematics achievement

Diamond (2013) describes EFs as: “skills essential for mental and physical health; success in school and life; and cognitive, social, and psychological development.” Diamond (2013) agrees that exist three components of EFs: working memory (WM) and inhibitory control distinguishing them from cognitive flexibility (the third), which “builds on the other two and comes in much later in development.”

Various studies have demonstrated the importance of EFs to the development of mathematical skills and shown that children with poor EFs can experience difficulties in various areas of mathematics (Viterbori, Traverso, & Usai, 2017). Further evidence demonstrates relations among EF skills and achievement through late childhood and early adolescence (e.g., St Clair-Thompson & Gathercole, 2000;). Usai and colleagues (2018) longitudinally investigated EF profiles in 5 years-old children and their later math achievement and showed that children with weak WM-shifting profiles (performed equally with typical EF profile group in arithmetic and math problems tasks in Grade 1) showed difficulties as a group of children with a general deficit in EFs in Grade 3. Viterbori and colleagues (2015) longitudinally analysed whether EF measured during the preschool period predicts math achievement in primary school. The results showed that the WM-flexibility component measured in the preschool period predicts math achievement in Grade 3. Math scores were predicted by WM-flexibility at both grade levels (Grade 1 and Grade 3). Problem-solving and arithmetical facts were predicted by the WM-flexibility component in Grade 3.

Considering the impact of different subcomponents of EFs on math achievement, WM has been extensively studied concerning mathematical achievement and abilities, revealing its involvement in performing arithmetical operations, and especially in the mental calculation (Passolunghi & Siegel, 2001, 2004). Various studies found that children who performed poorly in WM tasks did not reach the expected levels of math performance (Gathercole & Pickering, 2000; Geary, 2004; Passolunghi & Mammarella, 2010, 2012). The previous literature showed the influence of verbal WM (VWM) and visuospatial WM (VSWM) on math performance in different ages. According to some researchers, VWM has a larger role in math achievement compare with VSWM (Friso-van den Bos Van der Ven, Kroesbergen, & Van Luit., 2013). On the other side, a comprehensive study with a large sample of typical 9-year-olds with extensive battery measures showed the predictive role of VSWM, but not VWM on mathematical achievement (Szücs, Devine, Soltesz, Nobes, & Gabriel, 2014). The study by Giofrè and colleagues (2018) on middle-school students (in 6th to 8th grade) confirmed that VSWM predicts math performance and VWM predicts reading abilities. The different role of WM subcomponents on math achievement can be explained by the different tasks that were used as a measure for math abilities (De Smedt et al., 2009), but also with the differences in the age of the participants (Cragg Richardson, Hubber, Keeble, & Gilmore, 2017). Given the crucial role of WM in the learning process, it is fundamentally important to investigate the architecture of this function in more detail, especially as regards the complex interplay with other EFs.

While WM has been extensively studied, other EF's components such as inhibition and shifting have been much less investigated or indicate contradictory results (Blair & Razza, 2007; Yeniad, Malda, Mesman, Van IJzendoorn, & Pieper 2013). The relationship between inhibition and mathematical performance in preschool and school children has emerged in various studies (Usai, Viterbori, & Traverso, 2018). Bull and Scerif (2001) reported that the main difficulty for primary-school children lays in inhibiting a strategy already learned and switching to a new one. St Clair-Thompson and Gathercole (2006) partially confirmed the existence of several differences between EFs finding an important role of WM in English and math and the important role of inhibition in English, math, and science. Their study did not show results related to the shifting process in middle school students. On the other side, Cragg and colleagues (2017) investigated the role of EFs in factual knowledge, procedural skills, conceptual understanding, and overall math achievement in a sample with the age range between 8 and 25 years and found a significant relationship between VWM, VSWM, and overall math achievement, but did not found a significant relationship between inhibition, shifting, and overall math achievement. The explanation for their results was found in the evidence that inhibition and shifting account for less variance in math performance (Friso-van den Bos et al., 2013) but suggested that inhibition and shifting can contribute unique variance to math achievement when they are studied independently from measures of WM (Lee & Bull, 2015).

As a third aspect in the Diamond model, the shifting component seems to be relevant in math performance. Cragg and Nation (2009) conducted two experiments with children in different age groups and showed that younger children (5-8 years old) had greater difficulty inhibiting unrelated information than older children (9-11 years old). A meta-analysis conducted by Yeniad and colleagues (2013) highlighted the predictive role of shifting in performance in mathematics and reading across developmental ages. They showed an association between shifting and math performance and found that children with a greater capacity for shifting achieved better results in mathematics. They also provided a precise structure for classifying shifting tasks by level of complexity. The previously mentioned meta-analysis also showed the variety of tasks used to measure shifting, and the different scoring methods involved (reaction time, accuracy, efficiency, or combined scores). The shifting role was implicit in some studies and explicit in others.

As it is possible to observe previous studies showed contradictory results, a paucity of studies on middle-school students, and needs for more developmentally sensitive measures especially for shifting. Heterogeneity in the shifting tasks causes heterogeneity in the results obtained in previous studies because different shifting tasks used different dependent variables (Yeniad et al., 2013). On the other side, the predictability of WM measures across development makes these measures more stable compare with the measures for shifting (Ahmed, Tang, Waters, & Davis-Kean, 2018). To the best of our knowledge, no studies have yet examined the mediating role of VWM, VSWM, inhibition, and shifting (together) in a sample of middle-school students, leaving the influence of EFs on math achievement in this developmental period almost unexplored.

1.2. Mathematics anxiety and math performance

Cognitive aspects affect in shaping math performance, but an emotional component could also have a specific role in math performance (Mammarella, Caviola, & Dowker, 2019). Ashcraft (2002) defines math anxiety (MA) as "a feeling of tension, apprehension, or fear that interferes with math performance", and shows that individuals with more severe MA avoid situations in which they need to perform mathematical tasks. Such avoidant behavior can give rise to less competence, exposure, and practice, leaving students more anxious and mathematically less well prepared. Studies have shown a negative correlation between math achievement and MA (Ashcraft, 2002), and a lower quality of math learning in individuals experiencing MA (Dowker, Sarkar, & Looi, 2016).

To date, five meta-analyses have examined the relationship between MA and maths performance. In chronological order, the first two meta-analyses (Hembree, 1990; Ma, 1999) included several studies on secondary-school students, almost ignoring younger children. The recent meta-analysis (Namkung, Peng, & Lin, 2019; Zhang, Zhao, & Kong l., 2019) included a larger number of studies with primary school students. The last meta-analysis (Barroso et al., 2020) include adult samples, unpublish data, and conduct authors query for missing data that led them to have many more effect sizes. The fundamental aspect that came to light was that cognitive and emotional problems underlying math difficulties could be considered largely dissociable (Devine, Hill, Carey, & Szűcs, 2018).

The importance of more studies that investigate together EFs and anxiety and their influence on math performance will be discussed in the next section.

1.3. Anxiety and executive functions

Connections between EFs and anxiety have been examined particularly through the relationship between WM and anxiety (Eysenck & Calvo, 1992; Beilock & Carr, 2005; Mammarella et al., 2015; Passolunghi, Živković, & Pellizzoni, 2019). Stressful situations and negative feelings (such as anxiety) can interfere with success in mathematical performance (Caviola, Carey, Mammarella, & Szűcs, 2017). Attentional control theory (ACT), developed by Eysenck and colleagues (2007), describes anxiety as a disrupter of our ability to control our attention, which means that we are more readily distracted while performing a task. ACT thus suggests that anxiety reduces our cognitive capacity and impairs our efficiency, regardless of whether the stimuli that prompt it are internal (worrying thoughts) or external (tasks). According to this theory, anxiety influences WM and interferes with effective performance, particularly in complex tasks. Studies on adults assessing the joint influence of WM and MA on math performance generated contrasting results, and the literature offers different approaches. Ashcraft and Kirk (2001) suggested that individuals with a greater WM capacity have more cognitive resources and can manage anxiety-related thoughts and solve math tasks at the same time. Beilock and Carr (2005) took another view, claiming that individuals with a greater WM capacity are more susceptible to performance deficits as a result of WM disruptions (what they called a “choking under pressure” effect).

Most studies investigated only the relationship between MA and WM, without considering the role of other EF constructs. The studies were also conducted on primary-school children (Ramirez et al., 2013; Vukovic, Kieffer, Bailey, & Harrari, 2013) or adults (Beilock & Carr, 2005), leaving the years of early adolescence almost unexplored. The present study could be the first attempt to assess the influence of different EFs together with the emotional aspect (MA) on math performance and to observe how they are connected in the middle-school period.

1.4.The present study

In the present study, we examined the role of EFs (VWM, VSWM, inhibition, and shifting) and MA on math performance in middle school students, and we tried to reach the following aims: 1) to better examine the relationship between MA and maths performance; 2) to better examinee the relationship between EFs and math performance; and 3) to investigate the interplay between EFs (VWM, VSWM, inhibition, and shifting) and MA on math performances.

To achieve our aims, we hypothesized that:

1. MA would have a significant and negative relationship with math performance,
2. cognitive factors (VWM, VSWM, inhibition, and shifting) would have a significant and positive relationship with math performance,
3. there could be the direct and indirect influence of MA on math performance mediated through cognitive factors (VWM, VSWM, inhibition, and shifting) in middle school students.

Figure 1 shows the theoretical model based on the variables included in our study.

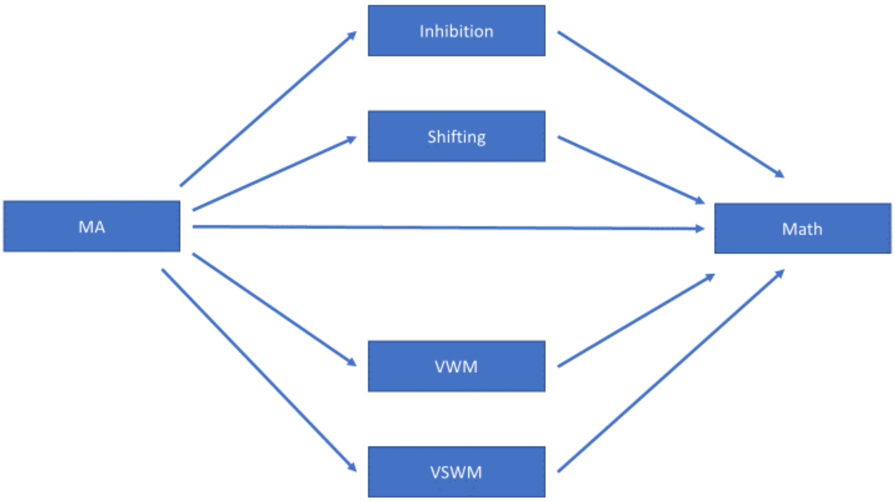


Figure 1. *Theoretical model*

To reach these aims students were assessed in two phases: during the first phase at the beginning of the school year, cognitive (VWM, VSWM, inhibition, and shifting) and emotional factors (MA) were tested. In the second phase, 7 months later, their maths abilities were tested. The order of the sessions and the order of the tasks (emotional, cognitive, and math performance) were the same for every participant.

1.5. Method

1.5.1. Participants

The research was carried out at four different middle schools in northeastern Italy. The study enrolled 105 middle-school students (48 males and 57 females; M_{age} = 12.623, SD = 0.6738), two of whom did not take part in the final assessment. None of the students were diagnosed with learning disabilities (the information that we get from the teachers). The final sample thus included 103 participants, all Caucasian. The sample's SES was primarily middle class, judging from the school records. A written informed consent form following the Declaration of Helsinki was signed by the student's parents and the school's principals. This study was conducted following the ethical guidelines of the Italian Association of Psychology and the ethical code of the Italian Register of Professional Psychologists.

1.5.2. Measures

1.5.2.1. Cognitive factors.

1.5.2.1.1. Verbal working memory.

The *Letters and Numbers Sequencing* subtest of the WISC-IV test battery (Wechsler Intelligence Scale for Children, 2003) was used to measure verbal WM. The test is designed to measure an individual's ability to retain and manipulate verbal information in their memory. After the examiner read a string of letters or numbers in random order, participants were asked to repeat them in alphabetical or numerical order. There were three pairs of strings (of letters and numbers) of increasing length, from two letters and two numbers to four letters and four numbers. The total raw score for the test is obtained by awarding 1 point for each correct answer and 0 for each wrong answer. The sum of the raw scores was converted into a scaled score using a specific conversion table.

1.5.2.1.2. Visuospatial working memory.

The *Dot Matrix* subtest (derived by Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001). A computerized version was used. This task measures the ability to simultaneously process visuospatial information and to maintain information in the visuospatial store. The task required the participant to verify a matrix equation while simultaneously remembering the location of the X in a 5x5 matrix. Each trial contains a set of matrix equations followed by a 5x5 matrix containing one X. As a matrix equation a simple symbolic addition equation was presented. Participants were given 4500 ms to verify the sum of two segments correctly or not described by a third presented pattern. Immediately after matrix addition, a 5x5 matrix with an X in a cell was displayed for 1500 ms on the screen. After a sequence participant had to recall (in any order) the appearance of X in the 5x5 matrix, by clicking in the empty 5x5 matrix with the mouse. The result presents the number of the X positions correctly recalled by the participant.

1.5.2.1.3. Inhibition.

The NEPSY-II Inhibition test (Korkman, Kirk, & Kemp., 2007) comprising two different trials (shapes and arrows), and three conditions: Naming, Inhibition, and Switching. For this study, we were interested in Inhibition and Switching conditions. For the condition Inhibition participants were presented with a series of black and white shapes (circles and squares) or black and white arrows pointing in a given direction and had to say as quickly as they can the opposite shape or direction. The standard score was used as a final score for this measure.

1.5.2.1.4. Shifting.

The NEPSY-II Inhibition test (Korkman, Kirk, & Kemp., 2007; Switching condition). Participants are asked to state the opposite shape if it is white, and the correct shape if it is black. The same with arrows (white arrow opposite direction, black arrow correct direction) and as quickly as possible. Before both conditions, participants did the example first. For each condition the response time, the number of errors, the number of self-corrections, and the sum of the number of errors and the number of self-corrections were recorded. The standard score was used as a final score.

1.5.3. Emotional factors.

1.5.3.1. Mathematics anxiety.

The Abbreviated Math Anxiety Scale (AMAS, Hopko, Mahadevan, Bare, & Hunt, 2003) is a self-report questionnaire containing 9 items adapted to middle-school students. The questionnaire uses a 5-point Likert scale on which participants indicated how much anxiety they would feel in a given situation that involves mathematics (1= little anxiety, 5= great anxiety). An example of an item is "Thinking about an upcoming math test 1 day before". The total score was the sum of all scores for each item, with a higher score corresponding to more severe MA.

1.5.4. Mathematical ability.

The AC-MT 3 (Cornoldi, Caviola, & Mammarella, 2020) is a test of mathematical calculation and problem-solving skills for students from 6 to 14 years old. This test examines different aspects of mathematical learning, written and oral calculus skills, the ability to understand and produce numbers, arithmetical reasoning skills, speed of calculation, and problem-solving skills. For the present study, we used five subscales (Approximate calculation, Fluency, Matrix, Inferences, and Written calculation). These five subscales were assessed in a collective way that was the reason that we choose them. For *Approximate calculation,* participants were shown an arithmetical operation and had to choose from a set of numbers which one comes closest to the correct result. They were allowed one and a half minutes to complete 15 exercises. For *Fluency*, participants saw the same series of operations and had to provide the correct answers as quickly as possible. They had three sheets, one of the additions (20 exercises), one of the subtractions (20 exercises), and one of the multiplications (20 exercises). For each sheet, they had one minute to complete the task. In the *Matrix* subscale, participants were shown 12 tables in which one cell was empty, and the task involved finding the right number to insert in each empty cell. They had two and a half minutes to complete the task. The *Inferences* subscale included three different exercises that involved finding missing numbers using mathematical reasoning. The total time available for the subscale was two minutes. For *Written calculation*, there were eight different operations (two additions, two subtractions, two multiplications, and two divisions) to be solved in 5 minutes. The tasks were presented in a paper-and-pencil format. Each correct answer scored one point, and the wrong answers scored zero. The sum of all subscales was used as a final score.

1.6.Results

1.6.1. Analytic strategies

SPSS IBM 21 was used to obtain the descriptive and correlation analyses between all measures. We conducted a bivariate correlation analysis using Pearson *r* between math calculation, EFs (VWM, VSWM, inhibition, and shifting), and MA for the whole sample. To explore our third hypothesis an indirect influence of MA mediated by cognitive factors on math calculation, path analyses were done with the lavaan package (Rosseel, 2012) for R (R Core Team, 2019).

The descriptive statistics of all tasks are reported in Table 1.

Table 1

Descriptive statistics of the tasks used in our Study

	Mean (SD)	Minimum	Maximum	Reliability
VWM	11.37(4.22)	1	23	.90
VSWM	.38 (.23)	.07	.98	.85
Inhibition	10.03(2.33)	1	15	.80
Shifting	9.67(2.78)	4	15	.80
MA	21.80(6.36)	9	38	.83
Math	45.94(11.87)	21	71	.73

† SD = standard deviation, VWM = Verbal WM, VSWM= visuo-spatial WM, MA=Math Anxiety

Bivariate correlations between mathematical performance, EFs, and MA are presented in Table 2.

Table 2

Bivariate correlations between all variables considered in the sample

	1	2	3	4	5	6
1. VWM	-					
2. VSWM	.314**	-				
3. Inhibition	-.061	.106	-			
4. Shifting	.075	.332**	.348**	-		
5. MA	-.136	-.110	-.090	-.260**	-	
6. *Math*	.188	.335**	.137	.446**	-.492**	-

† $^{**}p \leq .01$

‡ *VWM = Verbal WM, VSWM= visuo-spatial WM, MA=Math Anxiety*

Preliminary analyses included a test of a theoretical framework for better understanding the influence of cognitive and emotional factors on math calculation. In this theoretical model, we used cognitive factors as mediators (VWM, VSWM, inhibition, and shifting). We ran a path analysis and tested model fit considering: the chi-square ($\chi 2$), the comparative fit index (CFI), the normed fit index (NFI), the Tucker fit index (TFI), and the root mean square error of approximation (RMSEA); the chi-square difference ($\Delta\chi 2$), and the Akaike information criterion (AIC) were also used to compare the fit of alternative models (Kline, 2011). A priori power analysis (Gpower: Faul & Erfelder,1992) indicated that a sample size of 63 would be sufficient to detect a significant interaction effect with a power of .95 and an alpha of .05.

The statistical fit for the theoretical model was: CMIN = 13.75, *df* =4, CMIN/*df* = 3.43, *p* = .008, CFI = .883, NFI = .860, TLI = .560, RMSEA = .154, AIC = 1976.922, BIC = 2019.078. Results showed *Mathematical performance* to be significantly directly predicted by *VSWM* (*β* = .18; *p* = .038), *Shifting* (*β* = .29; *p* = .001) and, negatively, by *MA* (*β* = -.35; *p* = .000). Indirectly, significant and negative impact on *Mathematical performance* had *MA* through measure of *Shifting* (*p* = .024). Analysis, also, showed significant paths between *VSWM and Shifting* (*β* = .31; *p* = .002) and between *Shifting* and *MA* (*β* = -.28; *p* = .003). Also, results showed non-significant path between *MA* and *Inhibition* (*β* = -.09; *p* = .357), *MA* and *VWM* (*β* = -.11; *p* = .186), and between *MA* and *VSWM* (*β* = -.13; *p* = .259).

From the theoretical model we excluded all non-significant paths because we wanted to see if there will be changes in the fit indexes in a new model. Further, we ran the path analysis by testing for both direct and indirect influence, to show the influence of MA on math performance mediated by shifting. Model statistical fit was good: CMIN = 1.25, *df* = 1, CMIN/*df* = 1.25, *p* = .26, CFI = .996, NFI = .982, TLI = .976, RMSEA = .050, AIC = 1591.879, BIC = 1615.592. Results showed *Mathematical performance* to be significantly directly predicted by *VSWM* (*β* = .20; *p* = .018), *Shifting* (*β* = .29; *p* = .001) and, negatively, by *MA* (*β* = -.40; *p* = .000). Indirectly, significant and negative impact on *Mathematical performance* had *MA* through measure of *Shifting* (*p* = .033). Analysis showed significant path between *VSWM and Shifting* (β = .32; *p* = .002), and between *Shifting* and *MA* (β = -.25; *p* = .006). Results concerning direct and indirect influence and percentage of explained variance (R^2) are presented in Figure 2.

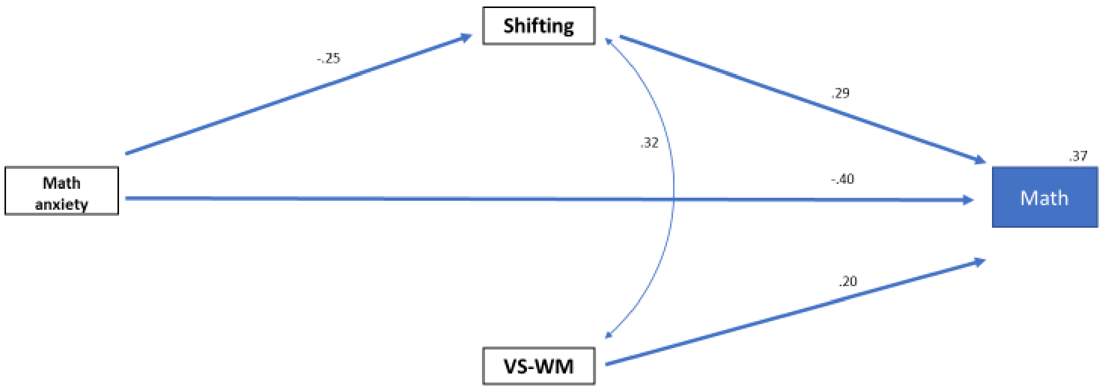


Figure 2. Final model

1.7. Discussion

Researchers have investigated the influence of cognitive and emotional factors on math performance on adults (Ashcraft & Kirk, 2001) and more recently in primary-school children (Ramirez et al., 2013), leaving mostly unexplored middle school students. The most investigated aspects were the influence of WM and MA, and rarely the influence of other EFs (e.g. inhibition and shifting) on math performance (Mammarella, Giofrè, & Caviola , 2017). Because of the lack of literature on the sample of middle school students, we designed the present study to understand more closely the importance of EFs and to investigate the reciprocal role of cognitive (WM, inhibition, and shifting) and emotional factors (MA) in mathematical performances. The goals of our study were to analyse: 1) the relationship between MA and maths performance; 2) the relationship between EFs and math performance;

and 3) the interplay between EFs (VWM, VSWM, inhibition, and shifting) and MA on math performances.

We hypothesized that MA would have a significant and negative relationship with math performance in middle school students. This hypothesis was confirmed and as expected the results showed a significant and negative relationship between MA and maths performance. The results are in line with previous studies in primary school students (Vukovic et al., 2013), in middle school students (Madjar, Zalsman, Weizman, Lev-Ran, & Shoval, 2018), and with adults (Ashkenazi & Danan, 2017).

The second hypothesis of the study was that cognitive factors (VWM, VSWM, inhibition, and shifting) have a significant and positive relationship with math performance in middle school students. This hypothesis has been partially confirmed. Results showed a positive relationship between VSWM and math performance and between shifting and math performance but not a significant relationship between VWM and math performance. Our findings agree with previous studies. Maybery and Do (2003) investigated the involvement of different components of WM in mathematical reasoning with the sample of 9-to 10-year-old children and the results showed that spatial memory was related more closely to math proficiency compare with VWM. A higher correlation was shown between fixed spatial span and each mathematics' domain than between fixed verbal span and each mathematics domain. Giofrè and colleagues (2018) showed that VWM and VSWM could be split regarding their predictive influence on reading and mathematics. The results of their study indicated the importance of VSWM for math, and the importance of VWM in reading. Also, some of the previous studies can be used for the explanation of our results, for example, the studies that underline the impact on math performance by depressing specifically VSWM resources (Soltanlou et al., 2019). The authors showed how MA appears to primarily impact the visual component (e.g., Trezise & Reeve, 2018). On the other side, Wong and Szücs

(2013) showed that maths tasks presented in a written format can inherently engage the visual components and had shown that format influences strategies that participants would choose (Katz, Bennett, & Berger, 2000).

In respect to inhibition, the study of Bull and Scerif (2001) with primary school students who had lower mathematical abilities showed that students had the main difficulty with inhibition of learned strategy and switching to a new one. In our study, the non-significant relationship between inhibition and math performance can be explained by the type of task that was used where the shifting task also has some inhibitory components on it. Students needed to inhibit previous learning strategies about forms and directions and after the inhibitory process to switch to a new strategy that includes colors (black and white). Also, most of the studies showed a significant relationship between inhibition and math performance-tested preschool children (Clark, Pritchard, & Woodward, 2010) but a small number of studies addressed this relationship in samples of middle school students (St Clair-Thompson & Gathercole, 2006). Differently from St Clair-Thompson and Gathercole (2006) our data do not present a significant relationship between inhibition and math performance but showed a significant relationship between shifting and math performance. In fact, in other studies, the inhibition task was used separately from the shifting task (Bull & Scerif, 2001). For future studies will be important to investigate the relationship between inhibition, shifting, and math performance in middle school students independently.

The third hypothesis was that MA can have a direct and indirect influence through the cognitive measures (VWM, VSWM, inhibition, and shifting) on math performance. This hypothesis has been partially confirmed, too. The indirect influence of MA through the cognitive measures was significant just for the measure of shifting, but not for the measures of VWM, VSWM, and inhibition. In other words, our results indicated that only shifting mediated the relations between MA and maths performance in middle school students.

Previous studies investigated the mediating role of WM in primary school (Justicia-Galiano, Martín-Puga, Linares, & Pelegrina, 2017) and middle school students (Owens, Stevenson, Hadwin, & Norgate, 2012), but not the mediating role of other EFs. As we already mentioned, different models tried to explain the influence of MA on math performance (Eysenck & Calvo, 2007). Another possible explanation is related to the nature of the math tasks used in our study. MA reducing the capacity of shifting influences math performance. Because of the negative influence of MA that consumes capacity for shifting participants showed lower results on the math tasks where they need to shift from one strategy to another. It is important to note that, as math tasks, we used five different tasks which involve various computational operations (addition, subtraction, multiplication, and division), but also inferences that require more involvement of shifting.

To the best of our knowledge, this is the first study that investigates simultaneously EFs and MA, and specifically found the mediating role of shifting in the relation between MA and maths performance in middle school students. This data seems to reflect a change in the developmental trajectory resulting in a specific role of shifting, during this specific developmental stage, compared to other EFs (St Clair-Thompson & Gathercole, 2006). We can speculate that the influence of EFs on math performance may change in middle school student's underling the critical role of shifting in this developmental stage (Miyake & Friedman, 2012).

Although our findings shed further light on the mediating role of EFs between MA and maths performance, this study also shows some limitations that should be taken into account in further research. First, we did not measure general anxiety, as a control variable of MA. The control variable will give a clearer view of the way that MA influences math performance. Second, task impurity is a major issue with EF components. In our study, we used a unique task from which we derived the measures of inhibition and shifting, and we used a task that includes numbers as a measure of VWM that can be discussed as task impurity (Denckla, 1994; Miyake et al., 2000). Third, we did not consider individual resources, such as self-concept, self-efficacy, motivation, and ego-resilience which have been shown important to mediate the relation between MA and maths performance (Donolato, Toffalini, Giofrè, Caviola, & Mammarella, 2020; Mammarella, Donolato, Caviola, & Giofrè, 2018).

EFs are important for the development of math skills and a deficit in the EFs can cause a delay in math learning (Bull & Lee, 2014). Our study confirmed the importance of VSWM and shifting for maths performance in middle school students and the necessity for the studies that will investigate separately WM from inhibition and shifting (Cragg et al., 2017). Thus, further longitudinal and experimental studies should be carried out to better determine the direction between cognitive and emotional factors and their influence on math performance, by also considering individual resources and environmental factors.

CHAPTER 2

The relationship betweens math anxiety and arithmetic reasoning: the mediating role of working memory and self-competence[2]

Mathematic ability is one of the most crucial skills that a person needs to master in life not only for a professional career in fields referring to Science, Technology, Engineering, and Maths (Dougherty, 2003) but also for properly mastering everyday activities, for personal wellbeing (Reyna et al., 2009). Given the importance of these abilities, it is fundamental to study and describe the factors that can promote or hinder the learning process at the base of this discipline. Previous studies have extensively investigated the cognitive abilities (intelligence, memory, processing speed) that prompt maths learning considered as general cognitive precursors (Giofré et al., 2017). On the other hand, other studies have evaluated the contribution of the emotional factors (e.g., general or specific anxiety) on maths performance (e.g., Donolato et al., 2020). Nevertheless, only a few studies have focused on the reciprocal influence between cognitive and emotional factors in the determination of maths proficiency, especially if referring to young children (Ramirez et al., 2013; Vukovic et al., 2013). Furthermore, researchers recognized the crucial role of motivational factors (e.g. self-competence) on maths success. Self-competence, as a part of global self-esteem, is defined as the evaluation of a child's effectiveness in different environments and has been documented to be a mediator between anxiety and achievement in different domains (Bracken, 1992; Donolato et al., 2019).

[2] Živković, M., Pellizzoni, S., Mammarella, I.C., & Passolunghi, M.C. (**submitted)**. Relationship between math anxiety and arithmetic reasoning: the mediating role of working memory and self-concept

Given the scarcity of the studies that have jointly investigated cognitive, emotional, and motivational factors in the literature, this study had the aims to 1) jointly evaluate the correlation between emotional, motivational, and cognitive factors - too often investigated separately- and arithmetic reasoning in the students of the 3rd, 5th, and 7th grades; 2) to investigate the mediating role of WM and self-competence to better understand the relationship between MA and arithmetic reasoning; 3) specifically to observe the possible relationship between working memory (verbal and visuospatial components) and self-competence.

2.1. Domain general cognitive abilities and maths domains

The general cognitive functions (e.g., intelligence and memory) include abilities on which multiple learning processes are grounded. Among them, a crucial factor is represented by working memory (WM) (De Smedt et al., 2009). This factor has a well-established effect on a variety of maths domains such as mental addition and subtraction (Mammarella et al., 2013), and problem-solving (Passolunghi et al., 2019). Furthermore, it is well established how children with poor WM are also weak in mathematics (Passolunghi & Siegel 2004).

The most well-known WM model is a tripartite model which includes a central executive, responsible for data storage, processing, and monitoring, and another two domain-specific systems devoted to processing either verbal or visuospatial information (Baddeley & Hitch, 1974). The episodic buffer was added as the fourth element of the model and presents the limited capacity system that provides and integrates temporary storage of information from the long-term memory and two subsystems (Baddeley, 2000). However, the episodic buffer is rarely studied in young children and even if researchers have proposed alternative models to explain WM functioning, such as a domain-general (Kane et al., 2004) or a domain-specific (Shah & Miyake, 1996), studies in developmental psychology indicate that the tripartite model can better explain the WM functioning (Giofré et al., 2017).

Recently, studies have focused on an intriguing debate on modality-dependent (verbal or visuospatial) stimulation of WM. Some research indicates a substantial correlation between the verbal (VWM) and visuospatial (VSWM) domains (Kane et al., 2004), while others observed this distinction in some ages, but not in others (Swanson, 2008). According to some studies, VWM is more likely to be related to reading attainment while VSWM is more related to maths performance (Giofrè et al., 2018). Soltanlou and colleagues (2015) showed a developmental perspective in this connection: VWM was the best predictor of multiplication performance in 3rd-grade students while VSWM was the best predictor of maths performance in the 4th grade. The previously mentioned literature indicates that it is fundamental to investigate the specific influence of VWM and VSWM according to the age and the type of task involved (Giofrè et al., 2018). In fact, a study conducted by Wong and Szücs (2013) showed that maths tasks presented in a written format can inherently engage the visual components and had shown that format influences strategies that participants would choose.

2.2. Influence of maths anxiety on maths performance

Maths anxiety (MA) is defined as “a feeling of tension, apprehension, or fear that interferes with math performance” (Ashcraft, 2002). The inverse relation between MA and mathematical achievement is well acknowledged (Barroso et al., 2020). This specific type of anxiety is so derailing that it causes emotional tension, decreases maths enjoyment, and induces less self-confidence concerning mathematics. These feelings induce avoidant behaviors arisen by math stimuli such as 1) drop out of maths tasks (see Ashcraft, 2002), 2) avoidance in taking maths exercises (Ashcraft, 2002), and 3) escaping from situations in which maths is requested (Ashcraft & Krause, 2007). This type of anxiety is specifically aroused by tasks and situations involving numerals and is dissociated from the form of anxiety associated with general testing settings (e.g. Ashcraft, 2002). Wu and colleagues (2014) observed a feedback loop in the relation between mathematical achievement and anxiety: the feeling of tension provokes avoidance and negative bias regarding actual competencies, which, in turn, leads to less enjoinment in practice. The lack of experience with maths activities determines less practice and, therefore, lower self-confidence, therefore boosting the anxiety feelings.

The detrimental role of MA on performance is well established in adults and older students (reaching a peak around the 4th grade), although the effects of MA may be observed from the first years of schooling (Ramirez et al., 2013; Vukovic et al., 2013). This data shows the early roots of this connection that calls for a specific evaluation of the developmental trajectory of this phenomenon.

The discussion on the theme, especially from a developmental perspective, raises another crucial topic: does MA determine a decrease in maths performance or, on the contrary, the scarce maths abilities affect the feelings experienced during task execution, as a result of repeated experiences of failure? A recent conclusive contribution, including a large sample of school children (Devine et al., 2018), suggests that cognitive and emotional mathematics problems largely dissociate. In fact, if children with developmental dyscalculia were twice as likely to have high MA compared with children with typical development, 77% of children with high MA would have typical or high mathematics performance. These findings suggest to closely look at the mechanisms underlying this relationship.

2.3. The modulating effect of WM on MA

Extensive evidence showed that the relation between MA and WM influences math attainment and to date, WM has been the most studied factor that could explain the relationship between MA and math performance. One of the theories that tried to explain the relationship between MA, WM, and performance is the processing efficiency theory (PET, Eysenck & Calvo, 1992). The PET was developed on Baddeley's model of WM and propounds the explanation that anxious thoughts (worries) influence WM by reducing WM capacity. Several studies showed the detrimental effect of MA on maths achievement by reducing the WM resources (Ashcraft & Kirk, 2001; Beilock & Carr, 2005). However, the specific profile of individuals more exposed to this effect is still a matter of debate. High WM abilities were proposed to have a protective role from the detrimental effects induced by anxiety. In this respect, Ashcraft and Kirk (2001) indicate that adults with higher WM could manage both maths tasks and anxiety-driven thought more successfully. More gifted WM individuals seem not to be affected by this type of connection. In particular, Miller and Bichsel (2004) observed that among the adults with high MA those with higher WM showed the best performance in calculation and problem-solving.

An alternative account proposes that individuals with high WM levels are more exposed to maths failure due to disruption caused by anxiety, especially in tasks solved under pressure. This happened presumably because of the consumption of cognitive resources otherwise devoted to the task resolution (Caviola et al., 2017). This phenomenon labeled "choking under pressure", has been described by Beilock and Carr (2005) in a series of studies on adults who were asked to solve demanding maths problems. The results indicate that people who rely more heavily on WM when solving the maths tasks showed lower maths performance, while participants who rely less on WM were less affected by MA when solving the maths tasks. Geary and colleagues (2004) showed the association between MA and maths achievement, only in children with high WM capacity because of the interaction of anxiety on the resource that children rely on to recover fundamental facts from long-term memory and to inhibit competing answers. There is a possibility that students with high WM capacity and high levels of MA switch their problem-solving strategies because of the influence of MA on WM (Ramirez et al., 2013).

It is crucial to note, anyway, that a growing literature on the field indicates that MA negatively impacts maths performance by depressing specifically VSWM resources (Soltanlou et al., 2015, 2019; Miller & Bichsel, 2004). The relevance of visuospatial WM in certain types of math tasks has already been shown students (Soltanlou et al., 2015), furthermore, a recent study suggests that children with higher math anxiety have less storage capacity for visual and spatial information (e.g. in solving multiplication problems, Soultanlou et al., 2019). In this sense, maths anxiety seems to play a greater role on VSWM than VWM in maths performance.

2.4. Influence of self-competence on math performance

In the beginning, the construct of self-concept was considered unidimensional, while at the end of the 20th century, Bracken (1992) developed a multidimensional model. Bracken (1992) defined self-competence as "active influence on child's environment, with their success or failure to solve the problem, achieve goals, determine desired situation, and function effectively; evaluation of child's effectiveness and competence in a different environment". This model investigates six domains of self-concept: affect, physical, family, social, competence, and academic. Eccles and colleagues (1998) showed a mediating role of self-competence in the achievement of different domains. Some authors reported that students who believe that they can solve the task that is in front of them showed better performance and higher motivation (Bandura et al., 1994). Self-competence is strongly correlated with successful learning and can also influence personal development and well-being. Students with positive beliefs about their mathematical knowledge will be highly engaged in maths activities. On the contrary, students with negative beliefs about maths will avoid maths activities, which means less maths practice and higher MA (Dowker et al., 2012; Ramirez et al, 2013). This tendency is present from early stages and a study (Clerkin & Gilligan, 2018) showed a significant positive relation between early numeracy and children’s confidence towards maths. Results indicated also a positive association with maths in the sample of the fourth graders, particularly for children from more socioeconomically advantaged families. A study, that longitudinally investigated the predictive role of cognitive (WM and intelligence) and motivational factors (self-perceived abilities and intrinsic values) on maths and German language in fourth-grade students, showed that cognitive factors are stronger predictors, but for the German language, motivational factors showed a stronger influence (Weber et al., 2013). Dowker and colleagues (2012) showed that children who self-rated themselves as higher performers are better in maths. These are the results that confirmed the positive relation between positive maths beliefs and maths performance in a way that children who believe more in their capacity to solve maths problems performed better in maths.

2.5. The present study

In the present study, we examined the role of working memory (visuospatial and verbal subsystem) and MA together with self-competence, on maths attainment, and we tried to reach the following aims:

1. Investigating the correlations between WM components (verbal and visuospatial), MA, self-competence, and arithmetic reasoning. Rarely considered together in a single study.
2. Determining whether VWM and VSWM and self-competence, have a direct or indirect effect in the relationship between MA and arithmetic reasoning, in order to

better analyse the underlying mechanism at the base of the relation between MA and maths achievement, extending and completing recent study in the field (Justicia-Galiano et al., 2017; Soultanlou et al., 2015).

3. Examining the specific interplay between VWM, VSWM, and self-competence, not fully investigated in previous studies (Justicia-Galiano et al., 2017).

We hypothesized that VSWM, but not VWM, had a more salient role in the interplay between MA and maths achievement, being particularly impaired by anxiety (Miller & Bichsel, 2004; Vukovic et al., 2013). We expected the direct influence of VWM, VSWM, MA, and self-competence on arithmetic reasoning (Donolato et al., 2019), and also an indirect influence of MA on arithmetic reasoning through the measures of VWM, VSWM, and self-competence (Justicia-Galiano et al., 2017). As for the third aim, we analysed the relationship between WM and self-competence with the hypothesis that the more a child has a positive self-competence, the higher the score on VWM will be (Donolato et al., 2019; Justicia-Galiano et al., 2017). The theoretical model is present in Figure 1.

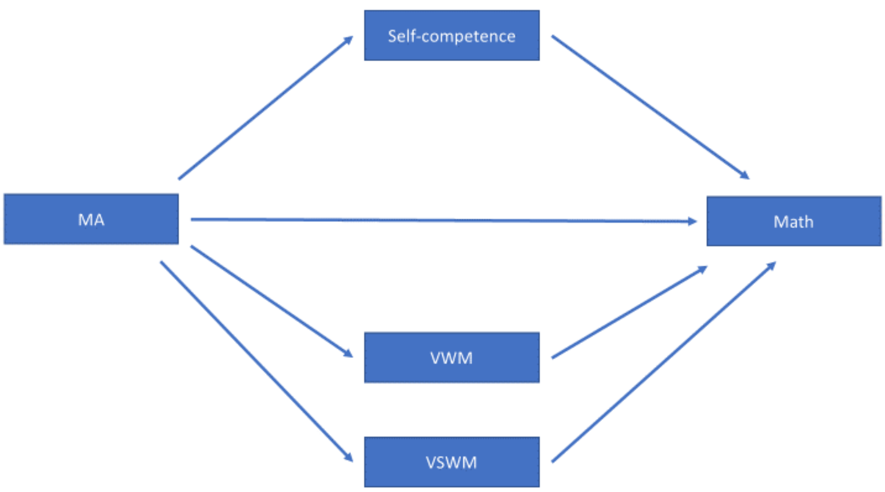


Figure 1. *Theoretical model*

To reach these aims students were assessed in two phases: during the first phase at the beginning of the school year, cognitive (VWM and VSWM), emotional (MA), and motivational factors (self-competence) were tested. In the second phase, 5 months later, their maths ability was tested. We explored the reciprocal relation between the variables of interest (i.e. MA, self-competence, VWM, VSWM, and maths achievement) by using path analysis models.

2.6. Method

2.6.1. Participants

The research has been carried out in seven different primary and two middle schools from the North-East part of Italy. There were 335 students who participated in the study (168 males and 167 females; 123 - 3rd graders, 109 - 5th graders, and 103 – 7th graders) with M_{age} (SD)= 10.54 (1.72). All participating students were Caucasian, the SES of the sample was primarily middle class as established by the school records. A written informed consent form following the Declaration of Helsinki was signed by the student's parents and the school's principals. This study was conducted following the ethical guidelines of the Italian Association of Psychology and the ethical code of the Italian Register of Professional Psychologists.

2.6.2. Materials

2.6.2.1. Cognitive factors.

2.6.2.1.1. Verbal working memory.

The *Digit span* (Wechsler Intelligence Scale for Children, 2003) presents one of the subscales of WISC IV where to the participant was read a sequence of numbers and asked to repeat the same sequence back to the examiner in order (forward span) or reverse order (backward span). There are two sets per trial, starting with two digits and going up to a maximum of nine digits. The test is interrupted when the child has repeated all the sequences or when he or she gets all the items in the sequence wrong. The total raw score for the test is obtained by awarding 1 point for each correct answer and 0 for each wrong answer. The sum of the raw scores was converted into a scaled score using the specific conversion table.

2.6.2.1.2. Visuospatial working memory.

The *Dot Memory task* (derived by Miyake et al., 2001). A computerized version of the task was used. In the subtest Dot Memory participants were asked to: 1) remember the location of two Xs that appear inside of a matrix, and 2) when the empty matrix reappears participants need to indicate the position of the X inside of the empty matrix. The result presents the number of the X positions correctly recalled by the participant.

2.6.2.2. Non-cognitive factors.

2.6.2.2.1. Maths anxiety.

The *Abbreviated Math Anxiety Scale* (AMAS, Hopko et al., 2003) is a self-report questionnaire with 9 items adapted to primary school students. This questionnaire is using a 5-point Likert scale where participants indicate how much anxiety they would feel in the situation that involved maths (e.g., 1= low anxiety, 5= high anxiety). An example of the scale “Listening to a lecture in math class”.The total score was the sum of all scores for each item, with a higher score corresponding to a higher level of MA.

2.6.2.2.2. Self-competence.

The *Multidimensional Self-Concept Scale* (Bracken, 1992) is a self-report scale for the assessment of self-concept in children and adolescents. This scale has six different subscales: Social, Competence, Affect, Academic, Family, and Physical. For the present study, we used subscale *Competence* (SC-C) to assess how participants perceived their ability to influence their environment, solve problems, or achieve their goals, respectively. The subscale consists of 25 statements scored on a 4-point Likert scale from 1 ("absolutely false") to 4 ("absolutely true"), higher scores indicate a more positive self-perception. Here, are reported some examples of items: "I am not as good as I should be" and "I am not very smart". To obtain the standard score of the subscale, the raw score is calculated and transformed into the total score using a specific conversion table, the total score with the specific conversion table will be transformed into the standard score. The standard score was used as a final score for this measure.

2.6.2.3. Mathematical ability.

2.6.2.3.1. Arithmetic reasoning.

The test that evaluates calculation skills and problem-solving (AC-MT 3, Cornoldi et al., 2020) was used to measure arithmetic reasoning, two paper-and-pencil subtests: Matrix reasoning and Inferences. Subtest *Matrix reasoning* assesses the ability to correctly reasoning about the properties of numerical series. Participants have to complete an incomplete numerical matrix with the correct number. This subtest for every grade has 12 assignments and one minute to be solved. *Inferences* investigate the ability to perform inferential mathematical reasoning, understanding of mathematical symbols, the degree of automation procedures, and fundamental principles of arithmetic. The subtest is divided into three different types of tasks: the first task requires operation performance with figures, in the second task, operations presented in Arabic format with the missing sign (+, -, ×, :) have to be completed, and in the third task there are pairs of operations, one incomplete and the other one similar already turned to the side. Participants are asked to resolve the first incomplete operation, not by doing the calculations, but by helping with the second operation already carried out, which offers a clue to the resolution of the first one. The subtest for third graders has 12 assignments that need to be solved in 2 minutes and 30 seconds. The subtest for fourth and fifth-grade students has 12 assignments: for the first task, participants have a minute, and for the second and the third task one minute. Both subtests have a time limitation. Each correct answer scored one point, and the wrong answers scored zero. The sum of all answers presents the raw score that was transformed into a scaled score using a specific conversion table for each grade. The sum of both subscales was used as a final score.

2.7. Results

2.7.1. Analytic strategies

SPSS IBM 21 was used to obtain the descriptive, correlation, and hierarchical regression analyses between all measures. We conducted a bivariate correlation analysis using Pearson *r* between arithmetic reasoning, cognitive (VWM and VSWM), emotional (MA), and motivational factors (self-competence) for the whole sample. Hierarchical regression analyses were conducted to investigate the influence of VWM, VSWM, MA, and self-competence on arithmetic reasoning.

To explore our main research question the reciprocal relation between the variables of interest (i.e., MA, self-competence, VWM, VSWM, and arithmetic reasoning) as our second hypothesis, path analyses were done with the lavaan package (Rosseel, 2012) for R (R Core Team, 2019).

2.7.2. Results

The descriptive statistics split by grade and reliability for all measures are reported in Table 1.

Table 1

Descriptive Statistics of all variables by grade

	3^{rd}	5^{th}	7^{th}	Minimum	Maximum	Reliability
N	123	109	103			
Age	8.62	10.79	12.58	8	13	
VWM	11.11 (3.17)	11.02 (3.15)	12.51 (4.64)	1	30	.85
VSWM	-.51 (.56)	.03 (.96)	.56 (1.12)	-1.22	3.70	.85
MA	23.21 (8.76)	23.29 (7.32)	21.77 (6.37)	9	44	.83
Self-Competence	52.63 (15.25)	48.90 (15.20)	47.25 (10.43)	0	97	.78
AR	-1.01 (2.10)	-.19 (2.38)	2.69 (2.53)	-5.53	8.04	.80

Note. VWM -verbal WM, VSWM – visuospatial WM, MA-math anxiety, AR- arithmetic reasoning

Bivariate correlations between arithmetic reasoning, cognitive (VWM and VSWM), emotional (MA), and motivational factors (self-competence) are presented in the Table 2.

Table 2

Zero-Order Correlations Between All Measures

	1	2	3	4	5
1. VWM	-				
2. VSWM	.153**				
3. MA	-.107	-.169**	-		
4. SC	.142**	.014	-.223**	-	
5. AR	.223**	.381**	-.224**	-.103	-

Note1. VWM – verbal WM, VSWM – visuospatial WM, MA - Math anxiety, SC – Self-competence, AR-Arithmetic reasoning

Note2. *p<.05; **p<.01,

To analyze how cognitive (VWM and VSWM), emotional (MA), and motivational factors (self-competence) can predict arithmetic reasoning, a hierarchical regression analysis has been carried out. Arithmetic reasoning was inserted as a dependent variable and the independent variables are: in the first block measures VWM (Digit span), in the second block measure VSWM (Dot Memory), in the third block measure for MA (AMAS), and in the fourth block multidimensional self-esteem questionnaire (TMA-Competence).

The model explains in total 23% of the variance of the performance in arithmetical reasoning. Hierarchical linear regression showed significant influence of measures for VWM (ΔR^2 = .049, *p* = .001), VSWM (ΔR^2 = .131, *p* = .001), MA (ΔR^2 = .024, *p* = .001), and self-competence (ΔR^2 = .030, *p* = .001) on arithmetical reasoning (see Table 3).

Table 3

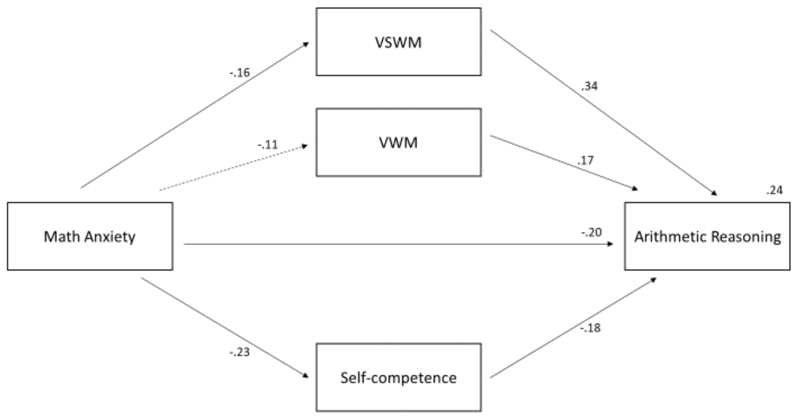
Hierarchical regression analysis

Independent variables (blocks)	R^2	ΔR^2	Sig.	β	p
1. VWM	.049	.049	.001	.222	.001
2. VWM	.180	.131	.001	.162	.002
VSWM				.366	.001
3. VWM	.204	.024	.001	.148	.004
VSWM				.343	.001
MA				-.159	.002
4. VWM	.234	.030	.001	.169	.001
VSWM				.336	.001
MA				-.199	.001
SC				-.178	.001

Note. VWM – verbal WM, VSWM – visuospatial WM, MA - Math anxiety, SC – Self-competence

After regression analysis path analysis was run for testing both direct and indirect effect, to show the effect of MA on arithmetic reasoning mediated by VWM, VSWM and self-competence. Model statistical fit was good: CMIN = 4.76, *df* = 2, CMIN/*df* = 2.38, *p* = .09, CFI = .977, NFI = .963, TLI = .885, RMSEA = .065, AIC = 6830.548, BIC = 6875.954. Results showed *Arithmetic Reasoning* to be significantly predicted by *Digit span* (*β* = .17; *p* = .001), *Dot memory* (*β* = .34; *p* = .000) directly and positively, and negatively by *Self-competence* (*β* = -.20; *p* = .000) and *Math anxiety* (*β* = -.18; *p* = .000). The analysis also showed indirect, significant and negative impact on *Arithmetic Reasoning* by *Math anxiety* through measure of *Dot Memory* (*p* = .006) and *Self-competence* (*p* = .006). Analysis showed significant path between *Digit span* and *MA* (*β* = -.11; *p* = .040), *Dot memory* and *MA* (*β* = -.16; *p* = .003) and between *Self-competence* and *MA* (*β* = -.23; *p* = .000). The percentage of explained variance (R^2) .24. (see Figure 2)

Figure 2. Path analysis



2.8. Discussion

Mathematical skills are essential to guide personal and professional choices, master everyday activities, and effectively exercise citizenship in a complex society. Given the relevance of this acquisition and the complex interplay between cognitive, emotional and motivational factors on maths performance, we investigated: 1) the correlation between WM components, MA, self-competence, crucial for arithmetic reasoning, but rarely jointly evaluated; 2) the mediating role of VWM, VSWM and self-competence in the relation between MA and arithmetic reasoning extending and completing a recent study (Justicia-Galiano et al., 2017; Soultanlou et al., 2015); 3) the correlation between VWM, VSWM, and self-competence, not fully investigated in previous studies (Donolato et al., 2019; Justicia-Galiano et al., 2017).

The present study ameliorates the assessment of MA and WM in several ways: first of all, we evaluated with reliable measures both VWM and VSWM in the attempt to disambiguate the specific role of both WM components on maths achievement and MA (Vukovic et al., 2013) and, secondly, we use a reliable and well-known scale to measure MA -Abbreviated Math Anxiety Scale- (Hopko et al., 2003).

Concerning the first objective, our data showed a significant and positive influence of VWM and VSWM on arithmetic reasoning and a negative and significant correlation between MA and arithmetic reasoning. Furthermore, a negative and significant correlation between MA and VSWM was observed but no significant correlation between MA and VWM emerged. Hierarchical regression analysis showed further detail of the relation between visuospatial and verbal components on arithmetic reasoning: VSWM had the strongest influence on arithmetic reasoning. Previous studies that investigated the relationship between MA and WM subcomponents showed mixed results. Some research used only the measure for VWM (Digit, Word, or Listening span) showing a significant correlation between VWM and MA (Ramirez et al., 2013; Justicia-Galiano et al., 2017), possibly due to the absence of VSWM measure in the design of the studies. One study used only the measure for VSWM (*Swanson Cognitive Processing Test* (*S-CPT*) visual matrix subtest, Vukovic et al., 2013) showing an early effect of MA on this component of WM. The studies that jointly evaluate VWM and VSWM are rare. One of these researches, with a developmental sample, was designed using the Letter span test as a measure for VWM abilities and the Corsi block tapping test for VSWM components. The authors showed the specific impact of anxiety only on VSWM (Soltanlou et al., 2019), but not on VWM. On the other hand, another study indicated a non-significant correlation between MA and VWM (Backward word and Backward digit recall) and between MA and VSWM (Path dual-task) (Cargnelutti et al., 2017).

Several studies, therefore, seem to point to a critical role of VSWM and MA on arithmetic reasoning as indicated in the model proposed by Miller and Bichsel (2004). The authors, in fact, showed how MA appears to primarily impact the visual component (e.g., Soltanlou et al, 2019). This tendency seems to be present also from a developmental perspective. Ramirez and colleagues (2013), and Vukovic and colleagues (2013) observed a specific impact of MA on VSWM from the very start of formal education. Our data has given further support to the previously mentioned studies (Miller & Bichsel, 2004; Ramirez et al., 2013; Vukovic et al., 2013) completing and enriching their perspective.

To evaluate the second objective, a path analysis was used to evaluate the direct and indirect role of WM (VWM and VSWM), MA, and self-competence on arithmetic reasoning MA had a significant indirect effect through the measure of VSWM (Dot Memory), but not through the measure of VWM (Digit span). This data seems to support previous work that underlines the impact on maths performance by depressing specifically VSWM resources (Miller & Bichsel, 2004; Soltanlou et al., 2015, 2019). and studies that confirmed the stronger influence of the "paper-and-pencil" format of maths task on VSWM compared with VWM (Wong & Szücs, 2013). The stronger effect of MA on VSWM possibly lies in the relevance of visuospatial components involved in both these factors (Ashcraft & Kirk, 2001), and in the type of math evaluation proposed to the children, "paper-and-pencil" format of maths task relay more on VSWM compared with VWM (Wong & Szücs, 2013).

Another interesting result of our study concerns the mediating role of self-competence on the relationship between MA and arithmetic reasoning. Specifically, as suggested by the social-cognitive theory of Bandura (1986) the self-competence has a mediation role in the research that investigated different influences on academic performance.

Consequently, this is one of the reasons why we decided to investigate together with VWM and VSWM the direct and indirect role of self-competence in the relationship mentioned above. Our results are consistent with the PET theory (Ashcraft & Kirk, 2001; Eysenck & Calvo, 1992). According to these approaches, in fact, higher MA children would display more worrying and thoughts about their self-competence which, in turn, would detract some of the VSWM resources necessary to successfully perform the tasks. In this respect, children have to increase their cognitive effort in order to compensate for their fewer resources but in certain circumstances children might not be willing to put in the extra effort required to succeed in the task. Our results are, also, in line with the study that longitudinally investigates the predictive role of cognitive and motivational factors in maths and the German language (Weber et al., 2013). The results showed cognitive factors as stronger predictors for maths performance and motivation factors as stronger predictors for the German language. In our study, the strongest predictor of arithmetic reasoning was a measure for VSWM. The study of Justicia – Galiano and colleagues (2017) investigated the mediating role of WM and math self-concept in the relation between MA and math performance in 3rd and 5th-grade students. The results confirmed the mediational mechanism of WM and math self-concept in the relation between MA and math performance and suggested that high math anxious children may believe that they are not capable to perform math tasks. In other words, their results suggested that MA and worry thoughts reduce math self-concept. Differently, Donolato and colleagues (2020) showed a positive effect of ego-resiliency on math performance and confirmed that ego-resiliency can be a protective factor for a child's math achievement. The study suggested that higher levels of ego-resiliency improve a child's ability to manage general anxiety, which reduces MA and test anxiety. In agreement with Justicia – Galiano and colleagues (2017) in our study self-competence does not act as a protective factor, but on the contrary, is depressed by anxiety and therefore negatively affects arithmetic reasoning. MA causes confusion and decreases the sense of competence loading our cognitive system also with intrusive thoughts ("I am not capable; I will never be able to do the task").

The third aim of the study was to observe the relationship between VWM, VSWM, and self-competence, which was not fully investigated in a previous study (Justicia-Galiano et al., 2017). The correlation analyses showed a significant relation between VWM and self-competence confirming the previous result, but not between VSWM and self-competence and this relationship was rarely investigated in the past. One of the explanations for this significant relationship between measures of VWM and self-competence could be seen in a stronger student's familiarity with a task that requires to remember a string of numbers, rather than self-evaluate the location of a symbol on a grid (Weber et al., 2013).

Our study also reveals some limitations: firstly, future studies should better analyse the influence of more complex measures of VWM and their relationship with emotional factors and arithmetic reasoning. It is worth noting that in our study our VWM measure was not a dual-task. Secondly, we did not use as a control, a measure of general anxiety. Even acknowledging these limitations, we think that the study has the strength to have considered self-competence, which did not show to act as a protective factor in mediating the relation between MA and arithmetic reasoning in the 3^{rd}, 5^{th}, and 7^{th}-grade students.

In conclusion, the present study confirmed a negative effect of MA on arithmetic reasoning (Barroso et al., 2020). The results showed the direct influence of cognitive factors (VWM and VSWM) (Mammarella et al., 2013), MA (Cargnelutti et al., 2017; Ramirez et al., 2013), and self-competence (Eccles et al., 1998) and underline the significant, indirect influence of MA through the measure of VSWM and self-competence on arithmetic reasoning. These results underline the importance of the interventions in monitoring not just MA, but also cognitive-motivational factors. In the light of the findings, however, we believe that this contribution may be of interest to the literature in the field by emphasizing that children's specific anxiety about doing maths adds a specific contribution that needs to be taken into account in the educational process, given the enduring effect of MA on learning. For this reason, as well as other trainings implemented on other specific cognitive functions, it would be relevant to devise specific interventions on self-competence from an early age, in order to work indirectly on maths anxiety, as well as on its negative effects on maths achievement.

CHAPTER 3

Math anxiety and math gender stereotypes in primary school students

Numerical abilities are an integral part of our daily activities, fundamental to understand and predict various aspects of a complex society. Math skills are related to school performance (see Watts, Duncan, Siegler, & Davies-Kean, 2014), employment opportunities, and socioeconomic status (SES) (Bynner, 1997; Gerardi, Goette, & Meier, 2013; Gross, Hudson, & Price, 2009; Rivera-Batiz, 1992) personal well-being (Gross et al., 2009; Furlong, McLoughlin, McGilloway, & Geary, 2016), the economic success for nations (Foley, Herts, Borgonovi, Guerriero, Levine, & Beilock, 2017; Peterson, Woessmann, Hanushek, & Lastra-Anadón, 2011). Given the relevant impact of numeracy on many aspects of individual and social life, it is fundamental to study the factors that promote or hinder mathematical skills from preschool onwards, thus reducing the risk of the onset of learning difficulties.

3.1.Math learning

International comparison of student achievement (OECD, 2018) showed that a growing number of students struggle with numbers and mathematical calculations, 24% of students did not reach the baseline of Level 2 (to extract relevant information from a single source and can use basic algorithms, formulae, procedures, or conventions to solve problems involving whole numbers). Furthermore, the report indicated that in mean terms boys outperformed girls in mathematics for 5 score points while in some nations this discrepancy reached 16 score points. The report (2018) indicates also that girls even when performed as well as boys showed less self-belief in their capacity for math learning, less openness to solve the problems, less motivation for math learning, and less persistence. In the sample of high-performing students in Italy, four boys are expected to work as an engineer before the age of 30, while one in eight girls expect the same. A very small percent of girls expects to work in ICT professions and 7%

of boys. These data call for an urgent and specific analysis of the factors that influence math abilities not only in cognitive but also in emotional and motivational terms. In this sense Math anxiety (MA) (Bieg, Goetz, Wolter, & Hall, 2015) together with specific gender stereotypes seems to be a good candidate to promote in-depth analysis of the theme (Vuletich, Kurtz-Costes, Cooley, & Payne,2020).

3.2.Math anxiety and math learning

Ashcraft (2002) defines MA as “a feeling of tension, apprehension, or fear that interferes with math performance” and suggested that individuals with high MA avoid situations in which they need to perform mathematical calculations. It has been extensively reported that a large proportion of children and adults have cognitive and/or emotional difficulties with mathematics (Hopko, McNeil, Gleason, & Rabalais, 2002). People who have higher levels of MA are more likely to avoid activities and situations involving math and for this reason, they have less practice (Ashcraft, 2002). Unfortunately, avoidance of math results in less competency, leaving students more anxious and mathematically unprepared to achieve (Dowker, Sarkar, & Looi, 2016). In the college and university environment, students with MA take fewer math courses and tend to feel negative towards math. Although MA is not the only variable that determines math achievement, it is a strong predictor even by controlling general anxiety (Wu, Barth, Amin, Malcame, & Menon, 2012; Wu, Willcutt, Escovar, & Menon, 2014). While the effects of MA have been extensively investigated in adults, in the last decades studies have focused also on key years of primary school, where children are introduced to formal math education (Wu et al., 2012; Ramirez, Gunderson, Levine, & Beilock, 2013; Vukovic, Kieffer, Bailey, & Harari, 2013; Namkung, Peng, & Lin, 2019). Research has suggested that a significant percentage of children in primary and secondary school suffer from MA, which is negatively impact on calculation skills (Passolunghi, Caviola, De Agostini, Perin & Mammarella, 2016; Cargnelutti, Tomasetto, & Passolunghi, 2016).

3.3. Math gender stereotypes

Eccles (2005) define math gender stereotypes as factors that affect gender difference in math-related abilities. There are different situations where students can approach math gender stereotypes, for example, stereotypic beliefs that express parents (Jacobs & Eccles, 1992; Tomasetto, Mirisola, Galdi, & Cadinu, 2015) or teachers (Tiedemann, 2002; Brey & Pauker, 2019). Some studies showed that children have awareness about gender stereotypes from the preschool period (Ruble, Martin, & Berembaum, 2007; Del Río, Strasser, Cvencek, Susperreguy, & Meltzoff, 2018). Cvencek and colleagues showed (2011), on the sample of 6- and 7-years old children, the existence of traditional gender stereotypes and Muzzati and Agnoli (2007) indicate a different developmental trajectory in stereotypical believes between males and females. In fact, during the second grade of primary school boys believe that there are no differences between boys and girls in math. But, by the third grade, they started to think that boys are somehow better in math than girls. During the fourth and fifth grades, students develop a very strong belief that boys are better than girls. On the other hand, girls have a different path, they started to believe from the second grade that they are better than boys in math, in the third grade they believe that there are no differences between girls and boys. The fourth-grade girls fundamentally changed belief and start to believe that boys are better in math. In the fifth grade, the influence of math gender stereotypes ("boys are better than girls in math") was strong even with an identical score on math performance. Passolunghi and colleagues (2014) investigated the influence of math gender stereotypes at explicit and implicit levels in 3rd, 5th, and 8th-grade students showing that if younger students (3rd graders express explicit math gender stereotypes, the older show stereotypic judgment only at an only implicit level, specifically in the 3rd- grade girls and 8th-grade boys.

Anyway not all researchers found stereotypical endorsement in math gender abilities many studies observed a relevant gender bias toward their gender, showing specific gender favoritism, from primary (Martinot & Désert, 2007; McKown & Weinstein, 2003; Yee & Brown, 1994) to eight grade (Morrissey, Hallett, Bakhtiar, & Fitzpatrick, 2019)

3.4.Gender differences in math anxiety

Various studies showed that feeling of tension towards math affects more women than men (Hembree, 1990; Miller & Bichsel, 2004; Devine, Fawcett, Szűcs, & Dowker, 2012; Ferguson, Maloney, Fugelsang, & Risko, 2015; Hill, Mammarella, Devine, Caviola, Passolunghi, & Szűcs, 2016). This seems to be due to different reasons: women are more likely to report it (Aschcraft, 2002), the influence of gender stereotype ("math is not for women", Beilock, Rydell, & McConell, 2007), genetic factors as a contribution to individual differences in MA (Hill et al., 2016). The studies (Devine et al., 2012; Van Mier, Schleepen, & Van den Berg, 2019; Sorvo, Koponen, Viholainen, Aro, Räikkönen, et al., 2017) underlines the importance of gender differences in the research of the effects of MA on math performance and showed the negative influence of MA in girls already primary school.

3.5. Anxiety and stereotype threat

The harmful effect that math-gender stereotypes can produce is recognized as a stereotype threat (Cadinu, Maass, Frigerio, Impagliazzo, & Latinotti, 2003; Muzzatti & Agnoli, 2007; Tomasetto, Alparone, & Cadinu, 2011; Maloney, Schaeffer, & Beilock, 2013; Ganley, Mingle, Ryan, Ryan, Vasilyeva et al., 2013). Stereotype threat can influence performance across the same mechanism as MA (Maloney et al., 2013). Steel and Aronson (1995) showed the negative influence of stereotype threat in the performance of Afro-American students, and Beilock and colleagues (2007) showed the same influence but in the sample of women. The study of Kiefer and Sekaquaptewa (2007) showed that implicit math-gender stereotypes moderate the effect of stereotype threat in women's math performance: the less influence of implicit-math gender stereotypes the better performance in math. The stereotype threat was reduced in the sample of women who did not influence stereotypes and they showed that exists the possibility to perform very well in math. Spencer and colleagues (2016) provide evidence that stereotype threat lean-to expands anxiety, with small evidence of the mediating role of anxiety for the stereotype threat. Their results suggested that emotional factors have an important influence on performance, moreover when stereotype threat is present. Researchers advise on the importance of in-depth analysis in the area of stereotype threats in the younger population (Osborne, 2001), given the importance of this type of effect at a developmental stage when the influence of stereotype threat becomes an issue.

3.6. The present study

The aims of the present study were twofold to 1. observe jointly the relation between MA, explicit math gender stereotypes, and arithmetic reasoning; 2. investigate the gender differences in MA, explicit math gender stereotypes, and arithmetic reasoning. We hypothesized that exist:

1. A significant relation between MA, explicit math gender stereotypes and arithmetic reasoning in students of 3rd, 4th, and 5th grade, and;
2. A significant gender differences in MA and explicit math gender stereotypes in primary school students (3rd, 4th, and 5th grade).

3.7. Method

3.7.1. Participants

The research has been carried out in seven different primary schools from the North-East part of Italy. In the study participated 376 students (198 males and 178 females; 132 - 3rd graders, 106 - 4th graders, and 138 – 5th graders) with M_{age} = 9.61 and SD = 1.05. All participating students were Caucasian, the SES of the sample was primarily middle class as established the basis of school records. Signed consent to participate in the study was obtained from the student's parents and the school's principals.

3.7.2. Materials.

3.7.2.1. Math anxiety.

The Abbreviated Math Anxiety Scale (AMAS, Hopko, Mahadevan, Bare, & Hunt, 2003, Italian version adapted by Caviola, Primi, Chiesi, & Mammarela, 2017) is a self-report questionnaire with 9 items adapted to primary school's students with two subscales: Math learning anxiety (5 items) and Math testing anxiety (4 items). An example of the item for Math learning anxiety is "Starting a new chapter in a math book", and an example of the item for Math testing anxiety is "Taking an examination in a math course". This questionnaire is using a 5-point Likert scale where participants indicate how much anxiety they would feel in the situation that involved math (e.g., 1=low anxiety, 5=high anxiety).

3.7.2.2. Explicit math-gender stereotypes.

The explicit math-gender stereotypes questionnaire (Muzzatti & Agnoli, 2007, adapted by Passolunghi & Tomasetto) that we used in this research has 3 items (i.e., According to your teachers, who is better at math between girls and boys?; According to your classmates, who is better at math between girls and boys?; In your opinion, who is better at math between girls and boys?). A five-point Likert scale was used where -2 means that "Girls are much better than boys" and 2 means that "Boys are much better than girls".

3.7.2.3. Cognitive factors

3.7.2.3.1. Verbal working memory

The "Letters and Numbers Sequencing" subtest of the WISC-IV test battery (Wechsler Intelligence Scale for Children, 2003) was used to evaluate the verbal WM. The test was designed to measure the individual ability to hold verbal information in memory while he/she manipulates it. The tests are administered verbally by the examiner according to the instructions in the manual.

The examiner read to a student series of letters and numbers and the student is required to repeat it, letters in alphabetical order and numbers in numerical order. There are three series for each sequence composed of one number and one letter, to arrive at a maximum of four numbers and four letters. The total raw score of the test is given by calculating 1 point for each correct answer and 0 points for each wrong answer. The sum of the raw score was transformed into the total score.

3.7.2.3.2. Visuospatial working memory.

The *Dot Matrix* subtest (derived by Miyake et al., 2001). A computerized version was used. This task measures the ability to simultaneously process visuospatial information and to maintain information in the visuospatial store. The task required the participant to verify a matrix equation while simultaneously remembering the location of the X in a 5x5 matrix. Each trial contains a set of matrix equations followed by a 5x5 matrix containing one X. As a matrix equation a simple symbolic addition equation was presented. Participants were given 4500 ms to verify the sum of two segments correctly or not described by a third presented pattern. Immediately after matrix addition, a 5x5 matrix with an X in a cell was displayed for 1500 ms on the screen. After a sequence participant had to recall (in any order) the appearance of X in the 5x5 matrix, by clicking in the empty 5x5 matrix with the mouse. The result presents the number of the X positions correctly recalled by the participant.

3.7.2.4. Arithmetic reasoning.

As a measure, we used a test that evaluates calculation skills and problem-solving (AC-MT 3, Cornoldi, Mammarella, & Caviola, 2020). For this study, we used two paper-and-pencil subtests: Matrix reasoning and Inferences. These subtests have a time limitation. *Matrix reasoning* assesses the ability to correct reasoning about the properties of numerical series. Participants have to complete an incomplete numerical matrix with the correct number. This subtest for every grade has 12 assignments and one minute to be solved. *Inferences* investigate the ability to perform inferential mathematical reasoning, understanding of mathematical symbols, the degree of automation procedures, and fundamental principles of arithmetic. The subtest is divided into three different types of tasks: the first task requires operation performance with figures, in the second task, operations presented in Arabic format with the missing sign (+, -, ×, :) have to be completed, and in the third task there are pairs of operations, one incomplete and the other one similar already turned to the side. Participants are asked to resolve the first incomplete operation, not by doing the calculations, but by helping with the second operation already carried out, which offers a clue to the resolution of the first one. The subtest for third graders has 12 assignments that need to be solved in 2 minutes and 30 seconds. The subtest for fourth and fifth-grade students has 12 assignments: for the first task, participants have a minute, and for the second and the third task one minute. Both subtests have a time limitation. Each correct answer scored one point, and the wrong answers scored zero. The sum of all answers presents the raw score that was transformed into a scaled score using a specific conversion table for each grade. The sum of both subscales was used as a final score.

3.8. Procedure

Materials were assessed in the classrooms in an anonymous form, every student had a code.

The study was conducted in three different sessions:

1. In the first session, we assessed non-cognitive factors: math anxiety and explicit math-gender stereotypes. This session was administrated collectively, the duration of

the session was 20 minutes. Tasks were administrated in the following order, first AMAS and after explicit math-gender stereotypes questionnaire;

2. In the second session, we assessed cognitive factors: verbal WM and visuospatial WM. In this session, participants were evaluated individually, in the quiet room at school. The session lasted 30 minutes;
3. In the third session, we assessed arithmetic reasoning. These tasks were administrated collectively, the session lasted 30 minutes. During the collecting session, the tasks were administrated in the following order: Matrix and Inferences.

3.9. Results

3.9.1. Analytic strategies

SPSS IBM 21 was used to obtain the descriptive, correlation, and multivariate analysis of covariance (MANCOVA) between all measures. We conducted a bivariate correlation analysis using Pearson *r* between arithmetic reasoning, cognitive (VWM and VSWM), emotional (MA), and social factors (explicit math gender stereotypes) for the whole sample. We conducted a multivariate analysis of covariance (MANCOVA), with the Gender (F and M) used as the fixed factor, Age as a covariate, and scores at MA, explicit gender stereotypes, and math abilities as the dependent variables. Bonferroni-adjusted pair-wise comparisons of gain scores were also carried out. For the comparison of gender differences, η_p^2 was used as a measure of effect size. Cohen's (1988) criteria were used to classify effect sizes: small effect: η_p^2 =.01; medium effect: η_p^2 = .06; and large effect: η_p^2 = .14.

The descriptive statistics and Univariate test results (from MANCOVA) split by gender are reported in Table 1.

Table 1
Descriptive Statistics and Univariate test results (from MANCOVA) for gain gender differences

	Boys	Girls	Minimum	Maximum	F	p	Reliability
N	212	186					
Age	9.59	9.64	8	12.3			
MA	21.71 (8.24)	24.29 (7.34)	9	44	10.083	.002	.83
EMGS	.20 (.87)	-.15 (.69)	-2	2	19.032	.000	.81
VWM	10.96 (3.58)	10.99 (3.46)	1	21	.011	.915	.90
VSWM	.28 (.20)	.24 (.17)	.00	.95	4.115	.043	.85
Arithmetic reasoning	-.28 (1.82)	-.32 (1.85)	-3.68	4.85	.269	.605	.70

Note. MA-math anxiety, EMGS-explicit math gender stereotypes, VWM-verbal WM, VSWM-visuospatial WM

Bivariate correlations between arithmetic reasoning, cognitive, emotional, and social factors are presented in Table 2.

Table 2
Bivariate correlations between variables considered in the sample

	1	2	3
1.Math anxiety	-		
2.Stereotypes	-.147**	-	
3.Arithmetic reasoning	-.145**	.046	-

Note. $^{**}p \leq .01$

Preliminary analysis yielded no statistically significant results for cognitive factors (verbal and visuospatial WM) between gender, $F_{(2, 371)} = .99$, $p = .11$, $\eta_p^2 = .449$. Therefore, these parameters were no longer included as covariates in the analysis.

MANCOVA results revealed a significant main effect of gender as fixed factor (Wilks' Lambda = .93, $F_{(3, 371)} = 8.74$, $p = .000$, $\eta_p^2 = .995$). More specifically, univariate test results showed a significant gender difference in the measure of AMAS, $F_{(1, 373)} = 10.083$, $p = .002$, $\eta_p^2 = .03$). Bonferroni-adjusted pair-wise comparisons indicated that both male and female participants showed the differences in AMAS, ($M_{diff} = -2.57$, $p = .002$, $d = .886$). Furthermore, the univariate analysis conducted on explicit gender stereotypes showed significant gender differences ($F_{(1,373)}$=19.032, p=.000, η_p^2 = .05), and Bonferroni-adjusted pair-wise comparisons indicated the differences in male and female participants (M_{diff} = .356, *p* = .000, *d* = .992). Univariate analysis for the measure of Arithmetic reasoning does not showed a significant gender differences ($F_{(1,373)}$=.269, p=.605, η_p^2 = .001) and Bonferroni-adjusted pair-wise comparisons confirmed results from Univariate analysis (M_{diff} = .094, *p* = .605, *d* =.081).

3.9.Discussion

The aim of the present study was twofold: 1. to jointly observe the relation between MA, explicit math gender stereotypes, and arithmetic reasoning and 2. to investigate possible gender differences in MA, Explicit math gender stereotypes, and arithmetic reasoning, considering WM (verbal and visuospatial) differences.

We hypothesized the presence of a relation between MA, explicit math gender stereotypes, and arithmetic reasoning in students of 3^{rd}, 4^{th}, and 5^{th} grade. The analysis showed a significant and negative correlation between MA and explicit math gender stereotypes, and a significant and negative correlation between MA and arithmetic reasoning while a correlation between explicit math gender stereotypes and arithmetic reasoning appears as not significant. Few studies in literature investigated the relationship between MA and explicit math gender stereotypes in the sample of primary school children (Tomasetto et al., 2011) and adolescents (Casad, Hale, & Wachs, 2015) showing that stereotype threat impairs performance on math tasks.

Anyway, these studies miss to include a math achievement measure in their experimental design observing only how emotional and social factors interplay. Our study tried to fill this gap showing firstly a negative correlation between MA and arithmetic reasoning that is in line with the well-acknowledged influence of MA on math performance in primary school children (Wu et al., 2012; Ramirez et al., 2013; Vukovic et al., 2013;

Cargnelutti et al., 2017) and secondly a complex interplay between MA and stereotypes on math acquisition. The lower MA the more stereotypic is the way participants think about math abilities (males are better than females), showing how cultural bias and emotional reaction to math could interfere with its acquisition.

Anyway, our data do not show a correlation between arithmetic reasoning and explicit gender stereotypes, this result could be due to the type of evaluation we proposed to children considering only the explicit component of the stereotypic bias (Passolunghi et al., 2014).

Regarding our second hypothesis, we suppose to find significant gender differences in MA and explicit math gender stereotypes in primary school students. Data show significant gender differences for MA and explicit math gender stereotypes, but not for the measure of arithmetic reasoning in absence of VWM differences, but with significant differences in VSWM (Levine, Huttenlocher, Taylor, & Langrock, 1999). Different studies showed a variety of possible causation of sex differences in VSWM, biological (without the possibility for the change) or environmental (can be reduced) (Halpern, Benbow, Geary, Gur, Hyde, & Gernsbacher, 2007). We can speculate that MA could influence VSWM, where girls showed a higher level of anxiety and a lower level of VSWM as observed in other studies (Ramirez, Gunderson, Levine, & Beilock, 2012).

Furthermore, data showed a higher level of MA in girls compared with boys in the primary school in line with the previous study (Devine et al., 2012; Van Mier et al., 2019; Sorvo et al., 2017; Hill et al., 2016) and a tendency for gender favoritism, already observed in other studies ((Martinot & Désert, 2007; McKown & Weinstein, 2003; Yee & Brown, 1994; Morrissey, Hallett, Bakhtiar, & Fitzpatrick, 2019). The analysis anyway did not show gender differences in the measure of math performance (Van Miller et al., 2019; Devine et al., 2012; Geary et al., 2019). This result indicates a decrease of gender differences in math, in line with a large population study conduct by Hyde and colleague (2008) where was shown that gender gap in math performance is not anymore large as it was in a meta-analytic study (Hyde, Fennema, & Lamon, 1990). Moreover, the meta-analysis (Else-Quest, Hyde, & Linn, 2010) showed very similar results and gender similarities in math achievement from PISA (Programme for International Student Assessment) and TIMSS (Trends in International Mathematics and Science Study) samples.

Our study has some limits. One of the most important is the lack of a measure for implicit math gender stereotypes and a measure of general anxiety as a control variable of MA. Furthermore, our sample is a sample of typical development children, without children with learning disorders. It will be very useful to investigate the influence of social factors on children with learning disorders, that are not present in the literature.

Even acknowledging these limits to the best of our knowledge this is the first study that investigates the influence of math gender stereotypes considering the measure of math and cognitive factors as control variables in 3rd, 4th, and 5th-grade students. Our study showed an important relation between emotional and social factors in the sample of primary school children. For future studies, it will be necessary development of a model that will investigate together cognitive, emotional, and social factors and their influence on math performance in the sample of primary school students.

CHAPTER 4

Math enjoyment or anxiety? The role of emotional and motivational contribution on math performance

Math achievement plays a fundamental role in the identity of an individual from a variety of aspects that goes from everyday activity, occupational and financial success (Bynner, 1997; Rivera-Batiz, 1992; Dougherty, 2003; Gerardi et al., 2013; Gross et al., 2009), aware citizenship, and general personal and social well-being (Gross et al., 2009; Furlong et al., 2015). Despite the well acknowledge the relevance of math achievement, the Programme for International Student Assessment (PISA), one of the most important international surveys of 15-year-old students' school achievement conducted in numerous countries all over the world (Organization for Economic Cooperation and Development OECD, 2013) showed that a growing number of students struggle with numbers and mathematical calculations. The data from the 2018 report showed that 24% of the survey's participants did not reach the baseline of Level 2 (to extract relevant information from a single source and can use basic algorithms, formulae, procedures, or conventions to solve problems involving whole numbers). Students performed poorly when asked to formulate mathematical situations, and they showed better results in applying and evaluating math outcomes. Furthermore, the report observed that 30% of students felt nervous or powerless when faced with mathematical problems, and also performed less well than expected in mathematics (OECD, 2013). This concerning phenomenon is even more extreme in some countries reaching 43% (OECD, 2013).

Given the complex situation, several studies have tried to identify which factors could promote or hinder math school success. At an individual level, the literature identifies several factors that influence math achievement: cognitive (intelligence, attention, WM, executive functions) (Giofrè et al., 2014; Passolunghi & Lafranchi, 2012), emotional (anxiety)

(Mammarella et al., 2018), motivational factors (self-efficacy, self-esteem, motivation) (Alivernini & Lucidi, 2011; Di Giunta et al., 2013; Justitia-Galiano et al., 2017).

If negative emotional components (e.g. math anxiety or general anxiety) have been extensively investigated (Hembree, 1988, 1990) positive emotions such as enjoyment have been much less evaluated. Furthermore, few studies have investigated the interplay between positive and negative emotions with self-efficacy. For this reason, the aim of this study is twofold 1. to better understand the relationship between general and math anxiety, positive emotions, and motivational aspects in the fifth-grade students, and 2. observe the quote of variance explained by emotional and motivational factors on math achievement.

4.1.The influence of positive and negative emotions on math performance

Among the emotional factors that influence mathematical performance, there are two that play a very different role: anxiety and math enjoyment.

4.1.1. General and math anxiety

Anxiety, defined as a "dispositional and dysfunctional response to a situation perceived as threatening" (Lewis, 1970). In the school setting, 10% of the children manifest this condition, which is observed starting from kindergarten (Egger & Angold, 2006). A high level of anxiety has been observed in children with learning difficulties or disabilities, typically described as more anxious than their classmates (Fisher et al., 1996). Even if the detrimental effect of the emotional factors, for example, anxiety, is acknowledged in children, its role on school performance is underestimated, in particular, if compared with that held by the cognitive abilities (Alloway & Passolunghi, 2011; Rohde & Thompson, 2007; St Clair-Thompson & Gathercole, 2006).

The assessment of general anxiety (GA), anyway, is still a critical issue in young children: probably due to the complexity of the construct, and its consequent self-evaluation has not high reliability. On the other hand, the assessment of anxiety provided by the teachers resulted to be a reliable measure of the children's emotional state (e.g., Kendall et al., 2007; Lyneham et al., 2008; Salbach-Andrae et al., 2009) and also a predictor of their math achievement (e.g., Cargnelutti et al., 2017a). In this sense, teachers' ratings can be considered a valid indicator of the students' anxiety state.

If the dispositional and dysfunctional response is aroused by a precise stimulus, it is possible to speak about a specific type of anxiety. Math anxiety (MA) is defined as a negative emotional response that occurs as a result of situations involving mathematics and can produce stress and avoidance behavior (Ashcraft & Ridley, 2005). It has been estimated that 17% of the population has high levels of MA (Ashcraft & Moore, 2009). Various studies investigated the influence of MA on mathematical learning, in different age groups from middle and high school students (Ma & Xu, 2004) to undergraduate students (Faust, 1996). The results of these studies showed that high levels of MA are linked to low performance in math. Researches in primary school students find a negative relationship between MA and mathematical performance (Cargnelutti et al., 2017; Owens et al., 2012; Sorvo et al., 2017; Wu et al., 2012; Ramirez et al., 2016). The development of MA leads to significant consequences, both short-term and long-term. For example, students with high levels of MA tend to avoid the courses and careers that include this discipline (Hembree, 1990; Ashcraft & Ridley, 2005; Maloney & Beilock, 2012), present negative attitudes towards math (Dowker et al., 2016; Gierl & Bisanz 1995) and maintain a negative perception of their mathematical skills (Ashcraft, 2002). Long-term consequences concern success and the decrease in employment opportunities during life (Dowker et al., 2016; Hembree, 1990; Ma, 1999; Zhang et al., 2019; Namkung et al., 2019; Barroso et al., 2020).

4.1.2. Enjoyment in math

The role of positive emotions in academic achievement crucial because of their contribution to self-regulation, motivation, and activation of cognitive processes (Pekrun et al., 2002; Aspinwall, 1998; Camacho-Morles et al., 2021). Compare with MA, described as a negative emotional response (Ashcraft & Ridley, 2005) (a negative emotion) enjoyment presents positive and high arousal emotion toward math (Pekrun et al., 2002). Enjoyment facilitates on-task attention and intrinsic motivation, and enjoyment will be experienced if the study process is perceived as interesting and intrinsically rewarding (Camacho-Morles et al., 2021). Pekrun (2000) described "The control-value theory of achievement emotions" (CVT) and analysed the effects of emotions on academic achievement from an integrative framework. Based on the control-value theory of achievement emotions various studies investigated the influence of achievement emotions on academic achievement in different age groups (Pekrun et al., 2006; Pekrun et al., 2017; Muis et al., 2015; Goetz et al., 2012; Bailey et al., 2014). The study that investigated relationships between student's perception of the math classroom environment, academic emotions (anger, anxiety, enjoyment, and boredom), and math performance in grades 5 to 10 showed that anxiety, anger, and boredom concerning math performance are differently affected by student's perception of the math classroom environment (Frenzel et al., 2007). Another study based on "the control-based theory of academic emotions" (Putwain et al., 2018) investigated the reciprocal relationship between enjoyment, boredom, and math performance in primary school children (5^{th} and 6^{th} grade) during the one full academic year in four proposing 4 waves. Mathematics achievement data were collected in the first (T1) and the third (T3) waves, while self-report data for enjoyment and boredom were collected in the second (T2) and in the fourth (T4) wave. They hypothesized that higher enjoyment and lower boredom in T2 influence positively math achievement in T3, and that math achievement could be positively related to enjoyment and boredom. Both hypotheses were confirmed. Also, a hypothesis that higher math achievement (T3) predicts higher enjoyment and lower boredom in T4 was confirmed. The findings confirmed the mediating role of enjoyment and boredom from T2 and T4 on math achievement (T3). This study confirmed a reciprocal relationship between emotions and achievement proposed by CVT.

The majority of the studies showed a moderate positive correlation between enjoyment and achievement (Goetz et al., 2010; Pinxten et al., 2014; Kim et al., 2014; Pekrun et al., 2017), In virtual high school, Kim and colleagues (2014) investigated the influence of cognitive, emotional, and motivational factors on math achievement. Findings important for our study showed a significant positive correlation between enjoyment in math and math performance, but also in multiple regression analysis enjoyment in math is a significant predictor of achievement. An interesting finding of this study is that self-efficacy was not a significant predictor of achievement when they used in account achievement emotions, and they explained results as moderation effect of achievement emotions on self-efficacy in the virtual classroom where students interact more with instructors and less with their peers. The cross-cultural study (Italy, Germany, and the USA) with second-and fourth-grade students have investigated the influence of enjoyment, boredom, and anxiety on math and native language (Raccanello et al., 2018). The findings showed a negative relation between anxiety and achievement, while positive relation was just between enjoyment and math. The younger students showed more enjoyment and less anxiety and boredom compare with older students. The results confirmed the complex role in achievement from both positive (enjoyment) and negative emotions (anxiety).

4.2.The influence of cognitive-motivational factor on math performance

4.2.1. Math self-efficacy

Bandura (1977) defined self-efficacy as belief in one's ability to succeed in achieving an outcome or reaching a goal. According to this approach, self-efficacy beliefs are formed from five sources: *performance experience* (previous and related experience with the subject), *vicarious experience* (observed performance and experience of others similar to oneself situation), *social persuasion* (verbal encouragement or discouragement about a person’s ability to perform), *imaginal experience* (imagination of the success at the task), and *physical and emotional states* (physical sensations and emotional states when a person facing the task) (Gosselin & Maddux, 2003). Bandura (1977) states that students with high math self-efficacy are more likely to be better in difficult tasks compare with their peers with low levels of self-efficacy. The educational efficacy of children presents a strong predictor of academic achievement (Schunk & Zimmerman, 1997), and the path of the operation of self-efficacy is very complex (Bandura et al., 1996). Bandura and colleagues (1996) proposed the complex causal structure of the paths that influence academic achievement through parental and children’s efficacy beliefs. Results of this research showed that parents with high self-efficacy hold high academic aspirations for their children. The social-economical status of families is in strong relation with academic efficacy and educational aspiration of parents, but also with low behavior problems, academic aspiration, moral disengagement, and academic achievement in children. Children’s academic efficacy beliefs were about peer acceptance, low level of emotional and behavioral problems, academic achievement. Pajares and Miller (1994) report that mathematical performance is reinforced by beliefs of self-efficacy. More recently had been shown that students who approach school with strong internal resources (such as self-efficacy) manage to engage more in mathematical learning and are better "equipped" to meet the challenges of the discipline (Martin et al., 2015). Longitudinal studies with middle and high school students showed self-concept and self-efficacy as important mediators of academic achievement (Skaalvik & Skaalvik, 2006).

Different studies showed a strong connection between math self-efficacy and performance (Collins, 1982; Hackett & Betz, 1989; Pajares & Miller, 1994; Lee, 2009). Collins (1982) investigated the relationship between levels of math performance (low, medium, high) and two levels of perceived self-efficacy in children (low and high). Results of this study showed that children who believed strongly in their capacity were faster to discard strategies. They performed better, they choose to rework more on the problems they failed and did so more accurately compare to children with the same abilities but with self-doubts. The study showed that positive attitudes toward math were better predicted by self-efficacy than by abilities that children have. Exploration of math self-efficacy showed a positive correlation between self-efficacy and performance, gender differences in math self-efficacy, and math self-efficacy as the only significant predictor of a math-related subject (Hackett & Betz, 1989). A cross-cultural study with PISA 2012 sample (England, Greece, USA, Hong Kong, Netherlands, and Turkey) investigated the influence of socioeconomic status, math self-efficacy, and MA on math performance in adolescents (Kalaycioglu, 2015). The results showed for all six countries that math self-efficacy has the strongest influence on math performance and negative relation between MA and math performance. If MA and math self-efficacy have been deeply studied in literature rarely, they were jointly evaluated in primary school children. These studies found a significant correlation between MA and math self-efficacy, and math self-efficacy was a significant predictor of math performance (Betz & Hackett, 1983; Hackett, 1985; Cooper & Robinson, 1991; Pajares & Kranzel, 1995; Jameson & Fusco, 2014). All of the studies as a sample had adults or adolescents. To the best of our knowledge, this is the first study that tries to investigate the relation between MA, math self-efficacy, and enjoyment in math in a sample of primary school children.

Given the scarcity of study that jointly evaluates anxiety, self-efficacy, and enjoyment in math the aims of the study were 1. to better understand the relationship between positive and negative emotions in the fifth-grade students; 2. and to observe how general anxiety, math anxiety, enjoyment in math, and math self-efficacy predict math achievement in the fifth-grade students.

Concerning the first aspect we hypothesized that MA positively correlates with GA (as already well established in the literature, Donolato et al., 2020; Passolunghi et al., 2019), and that MA negatively correlates with math self-efficacy, enjoyment, and math achievement and math enjoyment positively correlate with self-efficacy, and math attainment but negatively with MA and GA. In this study, GA was used as a control variable for MA, with the specific measure for MA we did not expect that measure of GA could have a predictive role. We were hypothesized that MA, independently from GA, can predict math performance in fifth graders.

Various studies investigated the predictive role of MA (Passolunghi et al., 2019), enjoyment in math (Putwain et al., 2020), self-efficacy on math performance (Pajares & Graham, 1999), but rarely in the literature can be found the studies that jointly investigate in the same model the predictive role of all these three very important constructs on math performance in primary school students (Stevens et al., 2006).

4.3.Method

4.3.1. Participants

The research has been carried out in five different primary schools, in eight fifth grade classes from the North-East part of Italy. In the study participated 145 students (84 male and 61 female) with M_{age} (SD)= 10.36 (.47). All participating students were Caucasian, the SES of the sample was primarily middle class, and established of the bases of school records. Written informed consent form under the Declaration of Helsinki was signed by the student's parents and the school's principals. This study was conducted following the ethical guidelines of the Italian Association of Psychology and the ethical code of the Italian Register of Professional Psychologists.

4.3.2. Materials

4.3.2.1.Math anxiety

The Abbreviated Math Anxiety Scale (AMAS, Hopko et al., 2003, Italian version adapted by Caviola et al., 2017) is a self-report questionnaire with 9 items adapted to primary school students. This questionnaire is using a 5-point Likert scale where participants indicate how much anxiety they would feel in the situation that involved math (e.g., 1=low anxiety, 5=high anxiety). The total score was the sum of all scores for each item, with a higher score corresponding to a higher level of MA. Cronbach alpha for this measure is .80.

4.3.2.2.General anxiety

The Revised Children's Manifest Anxiety Scale-Second Edition (RCMAS-2), Short Form (Reynolds & Richmond, 2008) consisting of 10 items that measure the level of general anxiety in children, with response YES-NO. An example of an item is "I feel nervous”. The raw score was transformed into a total score with a conversion table. The minimum score was 36, the maximum score was 77. Cronbach alpha is .70

4.3.2.3.Math self-efficacy

The Mathematical Self-Efficacy Scale (adapted by Caprara et al., 2011) presents a self-report questionnaire that measures the perception of mathematical self-efficacy. The scale is composed of 10 items with a Likert scale from 1 to 5 (from "completely good/bad" to "not at all good/capable"). The questionnaire investigates two domains: the capacity of perceived mathematics (an example of an item is "How good are you in the calculation?") and the capacity of perceived ability to self-regulate activities (an example of an item is "Can you concentrate on the study in math without getting distracted?"). The total score was the sum of all scores for each item, a higher score corresponding to higher self-efficacy. Minimum score 10, maximum score 50. Cronbach alpha is .82.

4.3.2.4.Enjoyment in math

The Achievement Emotions Questionnaire-Mathematics (AEQ-M; Pekrun et al., 2007) presents a multidimensional self-report questionnaire created to assess the emotions experienced by students in mathematics. This questionnaire contains 60 items that measure seven discrete emotions related to math: pride, anger, enjoyment, anxiety, shame, hopelessness, and boredom. Contexts of the scales are referring to experience's mathematical emotions in the situation of class attendance, study, and homework, and carrying out tests and mathematical examinations. For this evaluation was used the Enjoyment scale, consisting of 10 items with a Likert scale from 1 to 5 concerning the degree of agreement (from "strongly disagree" to "strongly agree"). An example of an item is "When doing my maths homework, I am in a good mood". The minimum score was 10, the maximum score was 50. The total score was the sum of all scores for each item, with a higher score corresponding to more enjoyment in math. Cronbach alpha is .81.

4.3.2.5.Math performance

As a measure of mathematics performance, we used a test that evaluates calculation skills and problem-solving (AC-MT 3 6-14, Cornoldi et al., 2020). For this study, we used three paper-and-pencil subtests: Fluency, Inference, and Written Calculation. These subtests have a time limitation. The Fluency task consisting of 7 additions, 5 subtractions, and 3 multiplications that need to be done in one minute. The Inferences task is divided into three different types of tasks: the first task requires operation performance with figures, in the second task it needs to be completed operations presented in Arabic format with the missing sign (+, -, ×, :), and in the third task there are pairs of operations, one incomplete and the other one similar already turned to the side. Participants are asked to resolve the first incomplete operation, not by doing the calculations, but by helping with the second operation already carried out, which offers a clue to the resolution of the first one. The Written calculation test consists of 8 operations (2 additions, 2 subtractions, 2 multiplications, 2 divisions) to be carried out in five minutes. The sum of all correct answers presents the raw score that was transformed into a scaled score using a specific conversion table. The sum of all subscales was used as a final score. Cronbach alpha is .80.

4.4. Procedure

Materials were assessed in the classrooms in an anonymous form. The study was conducted in two collective sessions (November 2019 and February 2020). In the first were assessed MA (AMAS), general anxiety (RCMAS 2), self-efficacy, and enjoyment (AEQ-M). The duration of the session was around 20 minutes. The three months after we assessed math performance tasks: Fluency, Inferences, and Written calculation. The session lasted about 20 minutes.

4.5.Results

4.5.1. Analytic strategies

All statistical analyses were performed by SPSS IBM 21. We conducted a bivariate correlation analysis using Pearson *r* between MA, GA, math self-efficacy, enjoyment in math, and math performance for the whole sample to test our first hypothesis. To examine our second hypothesis hierarchical regression analysis was conducted to analyse the influence of MA, GA, math self-efficacy, and enjoyment in math on math performance.

Descriptive analysis and zero-ordered correlation for assessed measures are present in Table 1.

Table 1. Descriptive Statistics and Zero-Order Correlations Between All Measures

	Mean (SD)	1	2	3	4	5
1.Math anxiety	21.64 (6.78)	-				
2.General anxiety	50.88 (8.40)	.353**	-			
3.Math self-efficacy	35.71 (6.48)	-.527**	-.194*	-		
4.Enjoyment	36.39 (7.91)	-.404**	-.243**	.388**	-	
5.Math performance	.93 (3.34)	-.466**	-.125	.458**	.335**	-

Note. *p≤.05; **p≤.01

In order to analyze our theoretical model, two hierarchical regression analysis has been carried out. In the first model, math was inserted as a dependent variable and the independent variables were in the first block measure for GA (RCMAS 2), in the second block measure for MA (AMAS), in the third block enjoyment in math (AEQ-M), and the final block math self-efficacy. In the second model, the same dependent variables as in the first model, but the blocks were different. In the first block measure for GA (RCMAS 2), in the second block measure for enjoyment in math (AEQ-M), in the third block MA (AMAS), and the fourth block math self-efficacy. With these two models, we wanted to see the possibility for the different predictive roles of positive and negative emotions on math performance.

The first model explains in total 29% of the variance of the performance in math. Hierarchical linear regression showed significant influence of measures for MA (R^2 = .22, p = .004) and math self-efficacy (R^2 = .29, p = .007) on math performance (Table 2.1).

Table 2.1
Hierarchical regression analysis

Independent variables (blocks)	R^2	ΔR^2	Sig.	β	p
1. GA	.021	.021	.100	-.146	.100
2. GA	.221	.200	.000	.026	.757
MA				-.479	.000
3. GA	.248	.027	.000	.046	.580
MA				-.414	.000
AEQ-M(E)				.180	.037
4. GA	.291	.043	.000	.042	.607
MA				-.286	.004
AEQ-M(E)				.130	.130
M - SE				.259	.007

GA-General anxiety; MA-Math anxiety; AEQ-M(E)-Enjoyment; M-SE-Math Self-efficacy

The second model explains in total 29% of the variance of the performance in math. Hierarchical linear regression showed significant influence of measures for MA (R^2 = .25, p = .004) and math self-efficacy (R^2 = .29, p = .007) on math performance (Table 2.2).

Table 2.2
Hierarchical regression analysis

Independent variables (blocks)	R^2	ΔR^2	Sig.	β	p
1. GA	.021	.021	.100	-.146	.100
2. GA	.117	.096	.000	-.068	.431
AEQ-M(E)				.319	.000
3. GA	.248	.131	.000	.046	.580
AEQ-M(E)				.180	.037
MA				-.414	.000
4. GA	.291	.043	.000	.042	.607
AEQ-M(E)				.130	.130
MA				-.286	.004
M - SE				.259	.007

GA-General anxiety; AEQ-M(E)-Enjoyment; MA-Math anxiety; M-SE-Math Self-efficacy

4.6. Discussion

Recent studies showed a negative relation between MA and math performance (Passolunghi et al, 2019), a positive relation between math self-efficacy and math performance (Pajares & Kranzel, 1995), and a positive relation between enjoyment in math and math performance (Frenzel et al., 2009). Anyway, to the best of our knowledge these factors have been never investigated jointly in a sample of primary school children. Previous studies investigate positive and negative emotions related to math performance in primary and middle school students with a longitudinal and cross-sectional design but did not investigate the type of anxiety, such as MA or general anxiety, in connection with motivational aspect or emotions on math achievement (Pekrun 2002, 2007; Putwain et al., 2020) in a specifically targeted age, fifth grade. In line with these considerations, our study has the main objectives 1. to better understand the correlations between positive (enjoinment) and negative emotions (math anxiety) in the fifth-grade students and 2. to observe which between GA, MA, math self-efficacy, and enjoyment in math could explain concurrently math achievement in the fifth-grade students.

Regarding the first aim that was to better understand the correlations between positive (enjoinment) and negative emotions (math anxiety) in the fifth-grade students data shows a negative and significant correlation between MA and enjoyment in math. Not surprisingly, students with high MA have less enjoyment in math confirming similar studies on the field (Collins, 1982; Bandura, 1997; Pajares & Krazel, 1995; Pajares & Graham, 1999; Skaalvik & Skaalvik, 2004; Wang et al., 2020; Zakariya, 2021).

Related to the second aim of the study we observe the role of GA, MA, math self-efficacy, and enjoyment in math on math performance. We design two different models for the hierarchical regression analysis to be sure that different block sequences would not influence the significance of variance explained. An important result is that both models MA and math self-efficacy indicate a significant concurrent quote of variance explained. Both the model data showed a negative influence of MA and a positive influence of math self-efficacy on math performance in fifth-grade students confirming similar results on the field (Owens et al., 2012; Ramirez et al., 2016; Cargnelutti et al., 2017; Collins, 1982; Hacket & Betz, 1989; Pajares & Kranzler, 1995; Pajares & Graham, 1999; Usher & Pajares, 2009; Zakariya, 2021).

In this study, we used the measure for GA in combination with MA, and results distinguish these two measures and showed that GA does not influence math performance in fifth-grade students. The results are in line with previous studies that showed that MA and GA have a small degree of shared components, but a large degree of unshared components (Malanchini et al., 2017; Wang et al., 2012). Findings from the study showed a negative influence of MA on math performance and confirmed the results from the studies that investigate the influence of MA on math performance in primary school children (Cargnelutti et al., 2017a; Ramirez et al., 2016; Passolunghi et al., 2019)

Concerning the analysis, we can speculate that the construct of math self-efficacy is a stronger predictor for math performance compare to enjoyment in math, as confirmed by previous studies on older students or adults (Pajares & Miller, 1994; Pajares & Graham, 1999; Zakariya, 2021). Furthermore, in our research, MA was assessed with more appropriate and reliable tools and we used specific and standardized math evaluation The previous studies investigate the influence of math self-efficacy on math performance usually in the sample of undergraduate students (Hacket & Betz, 1989; Pajares & Miller, 1994; Akin & Kurbanoglu, 2011), high school (Pajares & Krazler, 1995), or middle school students (Skaalvik et al., 2015; Sağkal & Sönmez, 2021), rarely in the sample of primary school students(Joët et al., 2011) as we did in our study.

Enjoyment in math had a positive correlation with math performance but did not show a significant influence on math performance in fifth-grade students. The literature on the field showed contrasting results, some studies indicate a positive correlation (Frenzel et al., 2009) but another highlights the absence of this link (Pekrun et al. 2006). Carver (2003) tried to explain the non-significant correlation between enjoyment and achievement arguing that when positive emotions arise, a signal that everything is going well is perceived and activity is no longer perceived as our priority. The "pre-ordering of priorities" situation shifts the attention and allocating the cognitive resources to other needs, compromising achievement and task performance. Another explanation of this absence of correlation could be found in the fact that that younger students (second grade) enjoy more in math than older students (fourth grade) (Raccanello et al., 2018). This data is confirmed by various longitudinal studies that showed a reduction in motivation in the transition from elementary to secondary school (Paulick et al., 2013; Raccanello & Brondino, 2016).

Also, Goetz and colleagues (2007) investigated the interrelation between academic achievement (math and language), self-concepts (math and verbal), and academic enjoyment

(enjoyment in math and verbal enjoyment), in students from grades 5 to 10. Academic achievement was assessed through final grades from the previous academic year, and self-concepts and academic enjoyment by self-report questionnaires. The results showed that academic enjoyment and self-concepts were largely uncorrelated. Positive domain-effect was found between academic achievement and enjoyment, and negative cross-domain effect on self-concepts that implies that influence of achievement on enjoyment was mediated by self-concept. This study is partially in line with our results because of the positive correlation between enjoyment in math and math performance but not on math performance the models that we investigated after are different.

We can assume that in this sample of student's stronger influence on math performance had negative emotion (MA) and cognitive-motivational factor (math self-efficacy), while positive emotion (enjoyment in math) showed a positive and a significant correlation with math performance, but not influence on math performance when the model was complete.

4.7. Limitations and strengths of the study

Our study showed some limitations. First, we used just self-report questionnaires for GA, MA, self-efficacy, and enjoyment that can be challenging for some children and results can be affected by social desirability bias. Second, our study was concentrating just on math performance, but it will be very useful for educational purposes to research the influence of anxiety, self-efficacy, and enjoyment on academic achievement not just in math. Third, our sample is typical children, we did not insert in the sample children with learning disabilities that will be very useful to see how positive and negative emotions influence their math performance.

Even with these limitations, the study also showed some important strengths. To our knowledge, this is the first study that investigated the influence of GA, MA, math self-efficacy, and enjoyment in math on math performance in primary school children as a unique model. The importance of the longitudinal design of the study is something that will be needed in the future for better understanding the influence of positive and negative emotions on math performance in younger children. Previous interventions try to reduce MA improving mathematical skills in primary school students. One of them is the study of Supekar and colleagues (2015) with the 8-set-week individual cognitive tutoring program in the third graders (age 7-9). The results showed that, after the conclusion of the tutoring period, there was a reduction in MA in the children who had a high level of MA before the start of the training and an improvement in arithmetic performance in problem-solving tasks. This study did not have a control group that is one of the limitations, also, very small sample size, and the assessment of simple addition testing tasks (e.g. 2+4=6). Passolunghi and colleagues (2020) tested two different training methodologies with a group of 224 fourth-grade students, dividing them into three groups that performed different activities according to the experimental condition: one group (N=76) that focused on identifying and overcoming feelings of MA, a second group (N=76) focused on improving calculation strategies through additional exercises, and finally the third group (N=72) as control training. The results indicated that both the training on mathematical strategies and MA contributed to a decrease in the level of the latter variable, but that only the training on mathematical skills led to a significant improvement in these skills. With our study we want to add that for future interventions it will be necessary to improve positive emotions and cognitive motivational factors, not just to reduce negative emotions as previous studies did (Supekar et al., 2015; Passolunghi et al., 2020).

CHAPTER 5

Training for improvement in math calculation

In the previous chapters, we demonstrated the influence of cognitive, emotional, cognitive-motivational factors on math performance in children from 8 to 13 years old. After the analysis of the data, we developed two training programs to improve math calculation skills. One training was developed for reduce of MA, and another for improvement of calculation skills (experimental groups) and one training about emotional recognition in everyday life (control group). Three classes of the fifth graders were asked to identify and copy MA-related feelings (N = 53). Three classes were asked about math strategy and group exercises to enhance calculation strategies (N = 51). Two classes (as a control group) were involved in emotional recognition training and the identification of emotions in everyday life (N = 36). We evaluated the differential effects of these training methods on MA, GA, self-efficacy, enjoyment in math, and math performance before and after the training. The follow-up was planned at the end of the school year.

Previous studies that investigated the possible influence of training to improve math performance concentrated primarily on cognitive factors (Bergman-Nutley & Klingberg, 2014; Karbach et al., 2014; Witt, 2011; Caviola et al., 2009) and less on emotional ones (Park et al., 2014; Supekar et al., 2015; Passolunghi et al., 2020).

The study of Park and colleagues (2014) showed a positive correlation between expressive writing and improvement in calculation tasks with a sample of university students with severe MA. Using short expressive writing as an intervention, they focused on reducing intrusive thoughts and improving the WM ability. The experimental group that used expressive writing as an intervention showed improvement in math performance immediately after the first session (especially students with high MA). Supekar and colleagues (2015) tested a group of students from 7-to 9-years old with intensive one-on-one math tutoring training with a duration of eight weeks (three sessions per week, duration from 40 to 50 minutes each). The training was based on the MathWise training method (Fuchs et al., 2013) for improvement number knowledge, increase counting speed efficacy, and application of calculation strategies. The results showed a benefit for severely math-anxious children. The research of Passolunghi and colleagues (2020) with math strategy intervention and MA training, as the experimental groups, showed some improvements. These math strategy training resulted in improvement of math ability (near transfer) and a decrease in MA levels (far transfer). MA training derived a decrease in the MA level (near transfer), but without improvements in math ability (far transfer). The limitations of the study were duration (only eight sessions, once a week for 60 minutes), absence of follow-up sessions, and math-related self-esteem and self-efficacy evaluations.

Our study was designed in three different trainings that went from general issues (understanding of the topic) to strategy applications (Figure 3). Each meeting with students was organised in a way that trainers described and explained what would be required during the meeting and the second part used playful activities or strategies to carry out the lesson. Training sessions took place once a week for a total of twelve 50-minutes sessions through the 2019/2020 school year. Pre-test evaluation was carried out between October 2019 and December 2019. Post-test evaluation was done immediately after the training, and follow-up in the last two weeks of the 2019/2020 school year.

The world COVID- 19 pandemic during 2020 caused us to not finish the three type of interventions (Table 1). The training "Reduction of math anxiety for better performance in math calculation" was finished but we did not have a possibility for the follow-up sessions. The training "Strategies and more practice in math, better performance in math calculation" had eight-sessions instead of twelve. The control group with the “Importance of emotions in our daily life” had only four sessions instead of the planned twelve.

Table 1. *Description of the training*

TRAINING	SAMPLE	MEASURES (pre-test, post-test, follow up)	Final results
Reduction of math anxiety for better performance in math calculation	N = 53 students (3 classes of the 5th grade) M = 28, F = 25 M_{age} = 10.48	Math Anxiety General Anxiety Math self-efficacy Enjoyment in math Math performance	Pre-test Post-test
Strategies and more practice in math, better performance in math calculation	N = 51 students (3 classes of the 5th grade) M = 30, F = 21 M_{age} = 10.48	Math Anxiety General Anxiety Math self-efficacy Enjoyment in math Math performance	Pre-test 8 of 12 meetings with students
Importance of emotions in our daily life	N = 36 students (2 classes of the 5th grade) M = 19, F = 17 M_{age} = 10.51	Math Anxiety General Anxiety Math self-efficacy Enjoyment in math Math performance	Pre-test 4 of 12 meetings with students

In this chapter, we will present the only training that had the pre-and post-test assessment with the title “Reduction of math anxiety for better performance in math calculation”. Measures were used for pre-test and post-test. As well preliminary results from this group of the students were made. This group of students (N = 53) was in fifth grade and training was focused on identifying and copying MA-related feelings. Fifty-three children (25 girls and 28 boys) took part in the research (Mean age = 10.48 years; SD = 0.38 years). From this initial group, 9 children were excluded from the study because they were absent on the day the post-test was administered. So, the final sample consisted of 44 children (20 females and 24 males), all of whom were present at more than 70% of the training sessions. Informed consent was signed by the parents of all children who took part in the study, before the start of the training, and verbal consent was obtained from the children at the time of the start of the activities.

The aims were to investigate the effects of MA training in modulating emotional states (near transfer) and mathematical performance (far transfer).

Our hypothesis:

1) reduction of MA occurs as a direct effect of the training (near transfer) in the participants with average and high levels of MA;

2) an improvement in mathematical abilities happens as a result of reducing the MA level (far transfer) in the participants with average and high MA levels.

5.1. Materials

5.1.1. Math Anxiety

The Abbreviated Math Anxiety Scale (AMAS, Hopko et al., 2003, Italian version adapted by Caviola et al., 2017) is a self-report questionnaire with 9 items adapted to primary school students. This questionnaire uses a 5-point Likert scale where participants indicate their level of anxiety in relation to situations that involve math (e.g., 1=low anxiety, 5=high anxiety). The total score was the sum of all points for each item, with a higher score corresponding to a higher level of MA. Cronbach alpha for this measure is .80.

5.1.2. General anxiety

The Revised Children's Manifest Anxiety Scale-Second Edition (RCMAS-2), Short Form (Reynolds & Richmond, 2008) consists of 10 items that measure anxiety in children, with YES-NO answers. Here's a sample statement "I feel nervous". The raw score was transformed into a total score with a conversion table. The minimum score was 36, the maximum score was 77. Cronbach alpha is .70

5.1.3. Math self-efficacy

The Mathematical Self-Efficacy Scale (adapted by Caprara et al., 2011) presents a self-report questionnaire that measures the perception of mathematical self-efficacy. The scale is composed of 10 items with a Likert scale from 1 to 5 (from "completely good/bad" to "not at all good/capable"). The questionnaire investigates two domains: 1. the capacity of perceived mathematics. For example, "How good are you in the calculation?". And 2. the capacity of perceived ability to self-regulate activities. For example, "Can you concentrate on the study in math without getting distracted?". The total score was the sum of all points for each item. A higher score corresponded to higher self-efficacy. Minimum score 10, maximum score 50. Cronbach alpha is .82.

5.1.4. Enjoyment in math

The Achievement Emotions Questionnaire-Mathematics (AEQ-M; Pekrun et al., 2007) presents a multidimensional self-report questionnaire created to assess the emotions experienced by students in mathematics. This questionnaire contains 60 items that measure seven discrete emotions related to math: pride, anger, enjoyment, anxiety, shame, hopelessness, and boredom. Contexts of scales refers to a mathematical emotional experience in the classroom, study/homework, and during tests/mathematical examinations. The Enjoyment scale was used for the evaluation, consisting of 10 items with a Likert scale from 1 to 5 concerning the degree of agreement (from "strongly disagree" to "strongly agree"). An example includes "When doing my maths homework, I am in a good mood". The minimum score was 10, the maximum score was 50. The total score was the sum of all points for each item, with a higher score corresponded to more enjoyment in math. Cronbach alpha is .81.

5.1.5. Math performance

As a measure for mathematics performance, we used a test that evaluates calculation skills and problem-solving (AC-MT 3 6-14, Cornoldi et al., 2020). We used three paper-and-pencil subtests: Fluency, Inference, and Written Calculation. These subtests had a time limitation. The Fluency task consisted of 7 additions, 5 subtractions, and 3 multiplications, each to be done in one minute. The Inferences task was divided into three tasks: the first required operation performance with figures; the second presented operations in Arabic format with the missing sign (+, -, ×, :); and in the third using pairs of operations, one incomplete and the other one similar already turned to the side. Participants were asked to resolve the first incomplete operation, not by doing the calculations of it, but by helping with the second operation already completed, which then offered a clue to the resolution of the first one. The Written calculation test consisted of 8 operations (2 additions, 2 subtractions, 2 multiplications, 2 divisions) to be carried out in five minutes. The sum of all correct answers presented the raw score that was transformed into a scaled score using a specific conversion table. The sum of all subscales was used as a final score. Cronbach alpha is .80.

5.2. Procedure

Materials were assessed in the classrooms in an anonymous form. The training consisted of four phases:

Phase 1 - at the end of October 2019 pre-test, a single collective session;

Phase 2 - early November 2019 to mid-February 2020, 12-meeting trainings;

Phase 3 - at the end of February 2020 post-test, a single collective session;

Phase 4 - end of May 2020 follow-up. It was planned but not implemented due to the COVID-19 health emergency.

5.3. Training

The training started in the last week of October 2019 and ended in the second week of February 2020. During this time there was one 50-minute meeting per week for a total of 12 meetings. The training always took place at school in the presence of the class teacher and consisted of lectures, readings, collective discussions, interactive activities carried out by the children both individually and in groups, homework and maths 'exams'.

Meeting 1: Introduction to the training and playful activities about the importance of mathematics in everyday and school life (example of activity: the story "The world without numbers").

Meetings 2, 3, 4, 5: introduction of the concept of emotions (what they are, when they are felt, how they manifest) and reading the story "The world without emotions". Introduction to the "emotional intensity scale" (example of activity: indicating the parts of the body where we experience emotions, describing situations in which they feel anxiety). Activities concerning emotions at school with particular reference to mathematics.

Meetings 6, 7, 8: introduction to the methods of emotional self-regulation. Activities included exercises at increasing awareness of the correlation between thoughts and emotions. An example includes, formulating possible negative and positive thoughts about a school event. The activities also included an analysis of emotional intensity during learning, and how they can switch from a negative into the positive thoughts. An example was a group game, and transforming negative thoughts, randomly drawn from a hat, - into positive ones.

Meetings 9, 10, 11: Maths “exams” (individual, relay, in pairs), sharing the emotions and using the strategies learned. An example of the activities, the transformation of negative thoughts using the emotional intensity scale.

Meeting 12: personal reflections shared with the group about the training. The final activity was “Scratch-art” cards when students could express their opinion in one or more sentences and/or make a drawing related to the training.

5.4. RESULTS

5.4.1. Analytic strategies

All statistical analyses were performed by SPSS IBM 21. In order to investigate the effectiveness. Wilcoxon tests were conducted for paired samples, comparing the group averages at time 1 (T1: pre-test) and with the group averages at time 2 (T2: post-test). Cohen's α was used to assess effect size (0.20 = small effect, 0.50 = medium effect, 0.80 = large effect, 1.2 = very large effect). An initial analysis of the total sample revealed no significant differences between the trials at T1 and T2 for any of the variables of interest, namely General Anxiety ($Z = -.094$, $p = .925$), Mathematical Anxiety, ($Z = -.799$, $p = .424$), Mathematical Learning ($Z = -4.335$, $p = .000$, $d = 0.57$) and Self-efficacy, ($Z = -1.369$, $p = .171$). It was then decided to divide the participants into three groups according to their MA scores on the pre-test: high MA (scores one standard deviation above the overall mean; N=8), medium MA (scores within the overall mean; N=27), and low MA (scores one standard deviation below the overall mean; N=9). The mean and standard deviations of the scores for the three groups are presented in Table 2.

	High MA (N=8)				**Average MA (N=27)**				**Low MA (N=9)**			
	PRE M (DS)	POST M (DS)	*Z*	*p*	PRE M (DS)	POST M (DS)	*Z*	*p*	PRE M (DS)	POST M (DS)	*Z*	*p*
Math Anxiety	31.63 (1.85)	31.75 (5.01)	.000	n.s.	21.89 (2.64)	19.52 (4.77)	-2.566	.010**	14.78 (1.30)	18.22 (5.68)	-1.548	n.s.
General Anxiety	54.25 (12.82)	56.00 (7.33)	-.677	n.s.	49.67 (5.99)	48.26 (8.56)	-1.153	n.s.	45.44 (8.85)	48.67 (9.81)	-.954	n.s.
Self-Efficacy	31.75 (4.53)	31.63 (8.25)	-.085	n.s.	35.37 (6.41)	33.82 (9.73)	-.782	n.s.	39.67 (4.24)	34.56 (8.08)	-1.540	n.s.
Math performance	9.38 (3.07)	11.75 (2.12)	-1.869	.062	14.00 (4.25)	17.56 (4.79)	-3.520	.000***	16.11 (6.72)	17.89 (6.95)	-1.279	n.s.

Table 2. Descriptive statistics

Note. *p≤.05; **p≤.01

Using a series of Wilcoxon tests for paired samples, the mean scores obtained in the tests of MA, General Anxiety (GA), Self-efficacy and mathematical performance in all three samples of children were compared:

a) *High MA* – GA: Z = -.677, *p* = .498; MA: Z = .000, *p* = 1.00; Self-efficacy: Z = -.085, *p* = .933; math performance: Z = -1.869, *p* = .062;

b) *Average MA* – GA: Z = -1.153, *p* = .249; MA: Z = -2.566, *p* = .010, d = 0.61; Self-efficacy: Z = -.782, *p* = .434; math performance: Z = -3.520, *p* = .000, d = 0.78;

c) *Low MA* – GA: Z = -.954, *p* = .340; MA: Z = -1.548, *p* = 1.22; Self-efficacy: Z = -1.540, *p* = .123; math performance: Z = -1.279, *p* = .201.

In Table 2 and Table 3, we conducted Pearson correlations between the level of GA (RCMAS), MA (AMAS), and Self-efficacy (SE) for the three groups: high MA, medium

MA, and low MA. A significant negative correlation between MA and self-efficacy was found in the group with low MA, both at pre-test (r = -.853, p = .003) and post-test (r = -.726 p = 0.27). A significant positive correlation between MA and self-efficacy was also observed in the children in the group with a high level of MA, both at the pre-test (r = .756, p = .030) and the post-test (r = .807, p = .015).

Level		RCMAS_PRE	SE_PRE	AMAS_PRE
High MA (N=8)	**RCMAS_PRE**	1	-	-
	SE_PRE	.484	1	-
	AMAS_PRE	-.098	**.756** *	1
Average MA (N=27)	**RCMAS_PRE**	1	-	-
	SE_PRE	-.039	1	-
	AMAS_PRE	-.078	-.316	1
Low MA (N=9)	**RCMAS_PRE**	1	-	-
	SE_PRE	.001	1	-
	AMAS_PRE	-.023	**-.853** **	1

Table 2. *Bivariate correlation between GA, MA, and self-efficacy (pre-test)*

Note. *p≤.05; **p≤.01

Table 3. *Bivariate correlation between GA, MA, and self-efficacy (post-test)*

Level		RCMAS_POST	SE_ POST	AMAS_POST
High MA (N=8)	**RCMAS_ POST**	1	-	-
	SE_ POST	-.139	1	-
	AMAS_ POST	.241	**.807** *	1
Average MA (N=27)	**RCMAS_ POST**	1	-	-
	SE_ POST	-.345	1	-
	AMAS_ POST	.047	-.350	1
Low MA (N=9)	**RCMAS_ POST**	1	-	-
	SE_ POST	-.426	1	-
	AMAS_ POST	.076	**-.726** *	1

Note. *p≤.05; **p≤.01

5.5. Discussion

The concept of MA has been studied for more than 60 years (Dowker et al., 2016) but the number of trainings created to reduce this form of anxiety is still low (Supekar et al., 2015; Passolunghi et al., 2020). Only two trainings have been offered to school children. The first is the program implemented by Supekar and colleagues (2015) that proposes specific mathematical activities to achieve a benefit on MA. The second was recently published by Passolunghi and colleagues (2020) and involves the use of two different training methods for two groups of fourth-grade primary school students: MA-reduction training that focuses on identifying and coping with feelings about MA, and math strategy training that focuses on additional exercises to improve calculation strategies. The duration of both was 8 meetings of 60 minutes each. The results showed that the MA training contributed to a decrease in the level of MA, although it did not affect mathematical performance. Near- and far-transfer effects were obtained through trainings that promoted the use of metacognitive strategies for solving mathematical tasks. There is a lack of interventions that put the focus on the emotional aspects that influence mathematical skills and not only on improving emotional control. The present study is in line with the proposal made by Passolunghi and colleagues (2020) with the pioneering aim of improving the effects of training on mathematical skills, overcoming the methodological limitations observed in previous training concerning the low number of meetings and the absence of emotional control exercises proposed to children during mathematics tests. In the training, strategies were proposed to the students, such as the controlling their negative emotions (anxiety) and reworking negative thoughts into positive ones to reduce the MA and use during the performance of a series of mathematical exercises carried out within the final sessions of the training. The activities implemented during the meetings allowed students to actively experiment strategies for reducing anxiety while performing mathematical tasks.

The present data shows that MA changed significantly only in the group with an average initial MA level. The group of students with a high MA did not undergo a significant change in the value of this construct. Probably it would be necessary to carry out longer trainings to address the interventions to smaller groups, rather than to the whole class, thus having the possibility of individualising the sessions, adapting them to the different levels of MA of the students in each group.

The results that regard GA had no significant difference between pre-and post-test in any of the three groups. This is not surprising, since the construct of GA can be considered stable and therefore very difficult to modify through such a short training period. Finally, no significant differences emerged between the groups concerning mathematical self-efficacy, in light of the absence of activities specifically devoted to this construct. Concerning mathematical abilities and comparing the pre-and post-test scores, it was possible to notice a significant improvement in performance for children with an average level of MA and an improvement that tended to be significant for those with a high level of MA.

Regarding the initial hypothesis (i.e., the ability to observe the effects of emotional training on the construct of MA (near transfer), it was, therefore, possible to find a reduction in this aspect only in the group with average levels of MA. Regarding the second hypothesis (an improvement of mathematical skills through a far transfer, as a consequence of lower level MA, such improvement was observed in the group with an average level of MA. This effect was partially confirmed for the group with a high initial MA level. These results are partially in agreement with those obtained in the recent study by Passolunghi and colleagues (2020), in which in the group subjected to emotional training indicated only a reduction in the level of MA (near transfer), while there was no change in mathematical skills (far transfer) for this group. The improvement in mathematical skills after training found in this study could be determined by the inclusion in the training not only of activities for the strengthening of emotional strategies but also for their use during mathematics tests.

Concerning the correlations between variables, the negative correlation between MA and self-efficacy found at pre-and post-test in the group of children with a low level of MA is in the line with the existing literature (Fast et al., 2010). A result that deserves particular attention is the positive correlation between MA and self-efficacy observed in students with a high level of MA. A possible explanation for this relationship between the variables could be that students with a high level of MA misattribute their mathematical learning abilities. In other words, these students may overestimate their mathematical abilities, and that anxiety increases concerning a perceived difficulty in performing tasks. This finding also suggests the importance of monitoring self-efficacy as highlighted by Fast and colleagues (2010). It is believed that being able to think about one's performance in an incremental sense, concerning specific starting skills, can be an issue for each student to consolidate individual self-efficacy. This suggests a way to counteract all those factors that the literature shows to be associated with disciplinary anxiety.

In summary, we can conclude that after the training there was a decrease in MA and an improvement in mathematical abilities in children with an average initial level of MA as well as a tendency to improve mathematical abilities in children with a high initial level of MA. No significant changes were found for any of the variables investigated in children who already had a low MA level at the beginning of the training.

5.6. Limitations and strengths

Several limitations are present.

One is the numerosity of the sample. We did the training with three classes of fifth-grade students. The second limit is the lack of a control group, whose data could not be collected due to the pandemic COVID19 emergency. This makes it impossible to establish, with certainty, the improvement in mathematical skills observed following the training and for what that improvement can be attributed. The third limit is the lack of follow-up measures - planned for the end of May 2020, again due to the interruption of school activities because of the pandemic, as well as the impossibility of using qualitative instruments to investigate the students' opinions about the training. We did not utilize a questionnaire to collect feedback on the recently concluded experience.

Despite these limitations, we believe that the research has potential, above all for having a near and far transfer on the population with an average level of MA. The objective for future work could be to confirm these results and to extend the duration of the training. It would be better to have meetings greater than 12 and work with smaller groups of students, possibly differentiated based on the initial level of MA reported by the individual. This would allow us to make interventions more targeted and individualized based on ability and need.

To conclude, MA has significant repercussions on many levels of individuals' lives, from the personal sphere (Ashcraft & Ridley, 2005; Hembree, 1990; Maloney & Beilock, 2012) to social aspects (Reyna et al, 2009; Ritchie & Bates, 2013). Because of the specific national condition on learning (PISA, 2012), it would be useful for teachers, parents, researchers, and institutions to make the best possible use of new methods to ensure the implementation of programs aimed at improving mathematical skills in future generations. Only through synergetic action involving institutions, parents, and children, will it be possible to contribute to the enhancement of mathematical skills, which are of great importance for the growth of knowledgeable citizens.

GENERAL DISCUSSION

Before the general discussion, I want to present to the readers the general structure of the Italian educational system, for a better understanding and more clear picture of the general results of the thesis. Italian educational system is mainly a public State system organised according to the principles of decentralization and autonomy of institutions. All schools that were part of the thesis are public schools. The Italian educational system includes early childhood and education care (from 0 to 3 and from 3 to 6 years old), primary, secondary, post-secondary, and higher education. Schools have a high degree of autonomy in defining curricula, spreading the educational offer, organising teaching (school time and groups of pupils), and every three years, schools prepare their own 'three-year educational offer plan'. The interesting part is territorial complexity of the Italian educational system that was already underline in the general introduction part, but it is important to underline here, too. Territorial complexity brings geographical differences in the academic achievement of students. Both, PISA (2018) and INVALSI (2019) confirmed the differences between regions from northern and southern parts of Italy, in a way that students from North Italy compare with students from South Italy showed differences in cognitive, emotional, cognitive-motivational, and social factors that influence performance in students. The participants for the thesis are from the northern part of Italy.

As already was shown mathematics is an extremely complex and multifaceted high-level discipline (Bull et al., 2008). Math performance presents a complex process that requires domain-general precursors such as intelligence and WM (Passolunghi et al., 2008; Passolunghi & Lanfranchi, 2012); attention (Passolunghi et al., 2005); inhibition and processing speed (Logie et al., 1994; Passolunghi et al., 1999; Passolunghi & Siegel, 2001, 2004); domain-specific precursors as number sense; general understanding of numbers as quantity discrimination; knowledge of symbols; and understanding of the positional value of digits (Passolunghi & Lafranchi, 2012; Caviola et al., 2014). Research has shown emotional factors as an important influence on math performance, such as MA (Ramirez et al., 2013; Gunderson et al., 2018; Wu et al., 2012; Ashcraft & Krause, 2007). Social and cognitive-motivational are also important factors for math performance but less investigated. This is the main reason why they were selected for this dissertation (Passolunghi et al., 2014; Tomasetto et al., 2011). The main aim has been to examine the relationship between cognitive (i.e., WM, inhibition, shifting), emotional (i.e., GA, MA, enjoyment in math), cognitive-motivational (i.e. self-efficacy, self-competence), social factors (i.e., explicit math gender stereotypes), and math performance and their influence on math performance.

On the other side, an important fact is that for a very long period influence of cognitive and emotional factors has been investigated separately. Only in the last twenty years have researchers examined these factors together and studied their influence on math performance clearer (Ramirez et al., 2013; Vukovic et al., 2013; Cargnelutti et al., 2017). The four related studies investigated the relationship between these different factors in typically developing children from 8 to 13 years old. The first study (Chapter 1) investigated the influence of EFs (VWM, VSWM, inhibition, and shifting) and MA on math performance in the sample of middle school students. Study 2 (Chapter 2) explored the mediation role of VWM, VSWM, and self-competence in the relationship between MA and arithmetic reasoning. Study 3 (Chapter 3) investigated the relationship between MA, math gender stereotypes, and arithmetic reasoning in the sample of 3rd, 4th, and 5th graders. And finally, Study 4, in the sample of fifth-grade students, investigated the influence of positive and negative emotions, and self-efficacy on math performance.

The main findings, the strengths, and the limitations, together with suggestions for further research for each study are summarized as follows:

Overview of research findings

The results from Study 1 confirms once again the presence of an influence that goes from emotional activation to maths attainment (Madjar et al., 2016; Kyttälä & Björn, 2014; Passolunghi et al., 2016), and underlines the importance of VSWM for math (Giofrè et al., 2018). To the best of our knowledge, this is the first study that investigates simultaneously EFs and MA and evaluates the mediating role of shifting in the relation between MA and maths performance in middle school students. This data seems to reflect a change in the developmental trajectory resulting in a specific role of shifting, during this specific developmental stage, compared to other EFs (St Clair-Thompson & Gathercole, 2006). We can speculate that the influence of EFs on math performance may change in the middle school period underling the critical role of shifting in this developmental stage (Miyake & Friedman, 2012). This study also shows some limitations that should be taken into account in further research: 1) the sample considered only children with typical development from 11 to 13 years old; none of the participants were diagnosed with specific learning disorders or other types of developmental difficulties; 2) we did not use the control measure for MA, such as general anxiety; 3) in the study was used unique task for the measure of inhibition and shifting, and the task that includes numbers as a measure of VWM can be discussed as task impurity; 4) we did not consider individual resources, such as self-concept, self-efficacy, motivation, and ego-resilience which have been shown to be important to moderate the relationship between MA and math performance. Study 1 points to the necessity of longitudinal and experimental studies to better determine the direction between cognitive and emotional factors and their influence on mathematical performance considering individual resources and environmental factors. Also, the sample that we used is not researched enough in the literature because not all educational systems (as the Italian educational system) have a middle school period. This study underlines the importance of this educational period and the need for more studies that will investigate the interplay of cognitive and emotional factors that influence math performance.

Study 2 confirmed a negative effect of MA on arithmetic reasoning (Barroso et al., 2020). The results showed the direct influence of cognitive factors (VWM and VSWM) (Mammarella et al., 2013), MA (Cargnelutti et al., 2017; Ramirez et al., 2013), and self-competence (Eccles et al., 1998) and underline the significant, indirect influence of MA through the measure of VSWM and self-competence on arithmetic reasoning. These results underline the importance of the interventions in monitoring not just MA, but also cognitive-motivational factors. In the light of the findings, however, we believe that this contribution may be of interest to the literature in the field by emphasising that children's specific anxiety about doing maths adds a specific contribution that needs to be taken into account in the educational process, given the enduring effect of MA on learning. For this reason, as well as other trainings implemented on other specific cognitive functions, it would be relevant to devise specific interventions on self-competence from an early age, in order to work indirectly on MA, as well as on its negative effects on maths achievement. The study has some limitations, too. First, the VWM measure was not a dual-task. Future studies should better analyse the influence of more complex measures of VWM and their relationship with MA and arithmetic reasoning. Second, we did not use, as a control for MA, a measure of general anxiety. Given these limits, the study considered self-competence, which did not perform a protective factor in mediating the relationship between MA and arithmetic reasoning in the 3rd, 5th, and 7th-grade students. These results reflect the importance of interventions in monitoring not just MA, but also cognitive-motivational factors. For this reason, as well as other training implemented on specific cognitive functions, it would be relevant to devise specific interventions on self-competence from an early age, to work indirectly on MA, as well as on its negative effects on maths performance.

Study 3 reported a significant and negative correlation between MA and explicit math gender stereotypes, as well as a significant and negative correlation between MA and arithmetic reasoning. A correlation between explicit math gender stereotypes and arithmetic reasoning results as not significant. Few studies have investigated the relationship between MA and explicit math gender stereotypes in the sample of primary school children (Tomasetto et al., 2011) and adolescents (Casad, Hale, & Wachs, 2015) showing that stereotype threats impair math performance. These studies did not include a measure for math achievement in their experimental design, reporting the only relationship between emotional and social factors. Our study attempted to partially fill this gap showing a complex relationship between MA, math gender stereotypes, and math performance. The lower the MA, the more stereotypic ideas participants have about math abilities (ex. males are better than females). The study shows how cultural bias and emotional reaction to math could interfere with its acquisition. The study did not show a significant correlation between arithmetic reasoning and explicit gender stereotypes. This result could be due to the type of evaluation we proposed to children considering only the explicit component of the stereotypic bias (Passolunghi et al., 2014). Data showed significant gender differences for MA and explicit math gender stereotypes. But there is little inequality for arithmetic reasoning in absence of VWM, but with significant differences in VSWM (Levine et al., 1999). Furthermore, data showed a higher level of MA in girls compared with boys in the primary school in line with the previous study (Devine et al., 2012; Van Mier et al., 2019; Sorvo et al., 2017; Hill et al., 2016) and a tendency for gender favoritism, already observed in previous research (Martinot & Désert, 2007; McKown & Weinstein, 2003; Yee & Brown, 1994; Morrissey et al., 2019). The study showed some limitations. The important one is the measure of math gender stereotypes where we measured for explicit math gender stereotypes without using an implicit measurement. Also, problematic, our study investigated the influence of these factors in the sample of typical children. Instead, it would be more useful to research the influence of social factors on children with learning disorders, studies that are not available in the literature. For future studies, it will be necessary to research the interplay of cognitive, emotional, and social factors and their influence on math performance in the sample of primary school students. Also, longitudinal studies and interventions could be very important for a better understanding of the relationships of these factors and the possibilities for the development of the interventions that will improve math skills in primary school children.

For Study 4 we can assume that the stronger influence on math performance had negative emotion (MA) and cognitive-motivational factor (math self-efficacy), while positive emotion (enjoyment in math) showed a positive and a significant correlation with math performance, but not influence on math performance when the model was complete. Concerning the analysis, we can speculate that the construct of math self-efficacy is a stronger predictor for math performance compare to enjoyment in math, as confirmed by previous studies on older students or adults (Pajares & Miller, 1994; Pajares & Graham, 1999; Zakariya, 2021). Furthermore, in our research, MA was assessed with more appropriate and reliable tools and we used specific and standardized math evaluation The previous studies investigate the influence of math self-efficacy on math performance usually in the sample of undergraduate students (Hacket & Betz, 1989; Pajares & Miller, 1994; Akin & Kurbanoglu, 2011), high school (Pajares & Krazler, 1995), or middle school students (Skaalvik et al., 2015; Sağkal & Sönmez, 2021), rarely in the sample of primary school students (Joët et al., 2011) as we did in our study. To our knowledge, this is the first study that investigated the influence of GA, MA, math self-efficacy, and enjoyment in math on math performance in primary school children as a unique model. The importance of the longitudinal design of the study is something that will be needed in the future for better understanding the influence of positive and negative emotions on math performance in younger children. The findings of the present study have important implications for the school context setting. They shed new light on how motivational and emotional factors can be associated with performance in math. The limitations of the study are 1) use of self-report questionnaires that can be challenging for some children, affecting the conclusions based on social desirability bias; 2) the study concentrated on math performance only. In the future, it will be helpful to research the influence of anxiety, self-efficacy, and enjoyment on academic achievement in general; 3) the study underlined the importance of a longitudinally designed study needed to better understand the influence of positive and negative emotional reactions to math (performance) in younger children.

EDUCATIONAL PRACTICE AND FUTURE DIRECTIONS

This dissertation focuses on the importance of diverse factors regarding math performance in students between 8 and 13 years old, also for education. The importance of EFs (VWM, VSWM, inhibition, and shifting) was highlighted and implied the usefulness of combining knowledge-based assessment with EFs measurements to obtain the options for each student regarding math performance. Our results support the suggestions that WM assessments may be useful predictors of later mathematical achievement and that WM screening in young children may help to identify students who are at risk of maths difficulties (Gathercole & Pickering, 2000, 2001). Also, there is a necessity for deeper investigation of an additional two EF components – inhibition and shifting in primary and middle school students.

School-based intervention programs, given available resources should help students develop new skills to achieve academic goals. Social-emotional programs in learning will help students to increase cognitive, affective, and behavioral competencies, making the learning process more enjoyable and with a sense of ease (Greenberg et al., 2003; Masia-

Worner et al., 2006; Ginsburg & Drake, 2002; Neil & Christensen, 2009). The strategies that promote well-being, such as coping skills, reduction of anxiety, improvement of self-esteem and self-efficacy are linked to individual progress (Collins et al., 2014; Gallegos et al., 2013). The future intervention to reduce MA in primary school children could have an extension of the duration and could be develop for work with a smaller group of students and give the possibility for more work on the individual level. Previous studies (Passolunghi et al., 2020) can be used as a starting point for the development of the school-based intervention that will improve math skills in primary school children. Also, we need more school-based interventions not only for the reduction of MA but for the improvement of math self-efficacy and math self-esteem in primary school students, important for math success.

Support and understanding of the importance of emotional and cognitive-motivational factors on the part of the parents and teachers are very important. They all play a very important role in supporting the interpretation of successful and effortful strategies that students can use in everyday situations (Gulliford et al., 2015). The active role of teachers in school-based programs may improve teachers' skills and teacher-student relationships.

Regarding cultural influences on math's success, this dissertation highlights the importance of gender-fair beliefs, without math gender stereotypes which cause a decrease in motivation for mathematics and a lower sense of self-competence. Practitioners who are interested in working with younger children need to be aware of the various influences that culture can have on the development of our knowledge and the strong influence of stereotypes in some cultures. It is important to educate parents and caregivers about the importance of a growing mindset and gender-fair beliefs (Lee et al., 2021).

To conclude, it is important to consider the variables that influence math performance in primary and middle school students separately, but also as a whole. Their interplay as factors will give practitioners a clearer picture of the strengths and limitations of each student. Together we can work toward positive outcomes of the development of mathematics for each student. The results of the dissertation underline, raise and clarify the relationship between cognitive, emotional, cognitive-motivational, social factors, and math performance but there are still open questions that require further studies.

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