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ARITHMETIC WORD PROBLEM-SOLVING IN PRIMARY SCHOOL CHILDREN: THE ROLE OF COGNITIVE AND EMOTIONAL-MOTIVATIONAL FACTORS

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DOTTORANDO / A
ELEONORA DOZ Eleonora Doz

COORDINATORE
PROF. ANDREA CARNAGHI

SUPERVISORE DI TESI
PROF. MARIA CHIARA PASSOLUNGHI

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Abstract

The ability to solve arithmetic word problems (AWPs) is a fundamental skill acquired during primary education and is recognized as a strong predictor of children’s academic performance, as well as their future occupational and financial success. Despite its importance, many children underperform in this area, highlighting the need to better understand the individual factors that affect AWP-solving ability and to develop evidence-based instructional interventions. While previous research has mainly focused on domain-specific cognitive skills underlying difficulties in AWP-solving, the role of emotional-motivational factors, such as math anxiety, and their combined effect with cognitive factors remains underexplored. Therefore, this dissertation aimed to broaden our understanding of the individual factors contributing to difficulties in AWP-solving among primary school children, by considering both cognitive and emotional-motivational factors, and developing targeted interventions. Specifically, the studies in this dissertation sought to: 1) assess the role of domain-general cognitive abilities in AWP-solving performance and problem representation; 2) investigate the relationship between math anxiety, metacognitive experiences of task difficulty, and AWP-solving; 3) evaluate how the interplay between math anxiety, working memory, and ego-resiliency affects performance on AWPs and an arithmetic task; and 4) compare the effectiveness of a cognitive-based intervention and an emotional-motivational intervention on AWP-solving ability. The results have demonstrated that cognitive factors, such as fluid intelligence, inhibition, updating ability, and reading comprehension, are important predictors of AWP-solving performance and problem representation. Furthermore, math anxiety was found to negatively impact AWP-solving performance, mediated by metacognitive experiences of task difficulty and working memory. Ego-resiliency showed a negative relationship with math anxiety, indicating its potential role as a protective factor against negative emotions in mathematical contexts. Finally, the findings suggest that a cognitive-based intervention, particularly one focused on problem representation, is more effective in improving AWP-solving ability compared to an emotional-motivational intervention targeting math anxiety. Both interventions significantly reduced reported levels of math anxiety. In sum, this dissertation highlights the importance of a holistic approach to understanding and addressing AWP-solving difficulties, emphasizing the importance of both cognitive and emotional-motivational aspects.

TABLE OF CONTENTS

2. STUDY ONE

3. STUDY TWO

4. STUDY THREE

5. STUDY FOUR

1. GENERAL INTRODUCTION

In today’s increasingly technological world, mathematical competence has become more critical than ever. Among the various mathematical abilities, solving arithmetic word problems (AWPs) holds particular importance (Vessonen et al., 2024). AWPs are typically defined as arithmetic problems presented in verbal form and embedded within real-world contexts, requiring individuals to apply arithmetic operations to answer one or more questions (Verschaffel et al., 2000). The ability to solve AWPs not only demonstrates a conceptual understanding of mathematics but also reflects an individual’s capacity to combine and apply this knowledge in everyday life (Fuchs et al., 2021; Verschaffel et al., 2020), making it a vital component of functional numeracy. It is not surprising, therefore, that proficiency in AWP-solving is a strong predictor of long-term outcomes, such as academic success, employment opportunities and wage levels in adulthood (Batty et al., 2010; Every Child a Chance Trust 2009; Hein et al., 2013). Given its significance, solving AWPs is a key skill emphasized in educational curricula worldwide (National Council of Teachers of Mathematics, 2000; Swanson et al., 2015).

Despite the importance of AWP-solving in educational settings and daily life, research consistently shows that many primary school children underperform in this area (Fuchs et al., 2014). For example, Carpenter et al. (1980) found that pupils performed 10 to 30% worse on AWPs compared to equivalent numerical expressions. More recently, data from the United States revealed that 56% of fourth graders scored at or below the basic level on the 2017 National Assessment of Educational Progress (National Center for Education and Statistics, n.d.). Similar trends are observed in Italy, where a significant proportion of students fail to meet minimum competency levels in word problems, with underperformance rates reaching 30% in primary schools (INVALSI, 2022). These patterns highlight the need to better understand the factors contributing to students’ difficulties with AWPs and underscore the urgency for evidence-based interventions to improve AWP-solving skills.

Research has identified three main contributors to difficulties in AWP-solving: task characteristics, individual characteristics, and environmental factors (see Daroczy et al., 2015). Regarding individual characteristics specifically, which are the emphasis of the present dissertation, a vast number of studies have explored the role of cognitive factors, such as reading comprehension and arithmetic skills (for a review, Jaffe & Bolger, 2023). Nevertheless, gaps remain in understanding how domain-general cognitive abilities, particularly fluid intelligence and executive functions, contribute to the AWP-solving process. In addition to cognitive factors, studies suggest that difficulties in math can also be attributed to emotional-motivational aspects (Živković et al., 2023). Among these, math anxiety (MA) has been shown to negatively influence math abilities by interfering with metacognitive processing (Efklides, 2011) and depleting working memory resources (Eysenck & Calvo, 1992; Ramirez et al., 2013, 2016). However, most studies have primarily focused on the effects of MA on general math achievement or basic math skills, such as calculation (e.g., Cuder et al., 2023; Korem et al., 2022). The specific impact of MA on AWP-solving performance has received relatively little attention, with most theoretical models of AWP-solving either neglecting emotional-motivational components altogether (Mayer et al., 1984; Kintsch & Greeno, 1985; Reusser, 1990; van Dijk & Kintsch, 1983) or acknowledging them without addressing them in depth (Daroczy et al., 2015). Similarly, also intervention studies designed to improve AWP-solving ability in primary school children have focused on cognitive aspects (e.g., Fuchs et al., 2020, 2021; Griffin & Jitendra, 2009; Powell et al., 2021), largely overlooking the effects of interventions addressing emotional-motivational factors (Passolunghi et al., 2020).

Given these gaps, the present dissertation project aimed to adopt a more holistic approach to understanding AWP-solving in primary school children by investigating both cognitive and emotional-motivational predictors. First, it examines the role of executive functions (i.e., inhibition and updating) alongside fluid intelligence and reading comprehension in AWP-solving, and more specifically in the construction of a mental model of the problem, using AWPs that vary in their demands for problem representation (Study 1). Second, it explores the influence of MA on AWP-solving, an aspect that has been largely overlooked by previous research. Specifically, Study 2 focuses on how MA hinders AWP-solving performance by investigating its relationship with metacognitive experiences of perceived task difficulties, while also considering gender differences. Study 3 extends this investigation by also exploring which factors might serve as protective buffers against MA. The study examines the interplay between MA, cognitive factors (i.e., working memory), and temperamental factors (i.e., ego-resiliency), while controlling for general anxiety and age. Furthermore, to enhance our understanding of these dynamics, the study compares their effects on both AWP-solving performance and arithmetic performance. Finally, this dissertation aims to contribute to the intervention literature by comparing two distinct approaches to improving AWP-solving performance: one focusing on cognitive strategies and the other targeting emotional-motivational factors, particularly MA. Using a randomized control trial design, Study 4 evaluates and compares the effects of these interventions in enhancing AWP-solving among primary school children, providing insight into potential causal mechanisms. Overall, this dissertation seeks (1) to deepen our understanding of both cognitive and emotional-motivational factors influencing children’s AWP-solving performance, expanding existing theoretical models of problem-solving, and (2) to assess the effectiveness of interventions targeting these dimensions.

1.1 Difficulties in AWP-Solving

A prominent theoretical model that comprehensively explains the difficulties in AWP-solving is the theoretical process model proposed by Daroczy et al. (2015). This model identifies three main categories of factors contributing to AWP-solving difficulties: task characteristics, individual characteristics, and environmental factors. Task characteristics involve linguistic and numerical features, as well as the interaction between these two, which determine the complexity of the problem. For example, research has consistently shown that the numbers of operations required to solve the AWP is a factor contributing to the difficulty—an example of a numerical feature that influences problem difficulty. Individual characteristics encompass students' capabilities, and according to the model are further divided into linguistic abilities, numerical abilities, and domain-general abilities. Environmental factors pertain to the teaching-learning environment and include variables such as the influence of teachers, textbooks, parents, and broader societal factors.

Central to this model is the assertion that task and individual characteristics influence students' performance both directly and indirectly through two mediating variables: cognitive load and problem-solving strategies. Cognitive load refers to the mental effort required to process information and is closely linked to working memory capacity (Sweller, 1988). As task complexity increases, so does cognitive load. Cognitive load is also influenced by individual differences, where students with higher cognitive abilities may experience lower cognitive load compared to those with poorer abilities. The second mediator, problem-solving strategies, involves the methods students apply when solving AWPs. The choice of strategies is influenced by both the features of the problem and the students' abilities and knowledge. Effective strategies can reduce cognitive load and enhance performance. Environmental factors further impact individual cognitive abilities, problem-solving strategies, and overall AWP-solving performance, by shaping the learning environment in which students develop these skills.

1.2 Individual Factors Influencing AWP-Solving

This dissertation expands upon the theoretical process model proposed by Daroczy et al. (2015) by focusing on the individual characteristics that significantly influence AWP-solving performance in primary school children. While the original model emphasizes cognitive abilities—namely linguistic, numerical, and domain-general skills—this dissertation aims to enrich the framework by integrating emotional-motivational factors, which have increasingly been recognized as crucial contributors to success in AWP-solving (Caviola et al., 2022; Passolunghi et al., 2019). An overview of the key cognitive and emotional-motivational factors that play a pivotal role in AWP-solving performance is provided below.

1.2.1 Cognitive Factors

AWPs are classified as higher-order mathematical tasks (Duque de Blas et al., 2021) that involve several processes. According to Mayer and colleagues (Mayer, 1992; Mayer & Hegarty, 1996; Mayer et al., 1984), these processes include translation, integration, planning, and execution. During the translation phase, the solver reads the problem and translates each statement of the problem's text into a propositional mental representation. During the integration phase, the problem solver integrates information across sentences and connects all solution-relevant elements into a coherent mental representation of the problem situation, also known as *problem model*. The problem model is an ad hoc representation constructed in working memory, and its structure captures the relationships between the various elements described in the problem (Thevenot, 2010). For example, the sentence "the banana is to the left of the plate" can lead to the model "B–P", where the linguistic expression "to the left of" is no longer represented. During the planning phase, the problem solver develops a plan for solving the problem by integrating existing and new knowledge (Boonen et al., 2016; Hegarty et al., 1995; Kintsch & Greeno, 1985) and recognizes which operation to apply. During the execution phase, the problem solver carries out the planned arithmetic computations. Finally, the model also acknowledges the significance of a metacognitive component, wherein the solver reflects on the obtained results (Mayer, 1998). Metacognition, defined as knowledge and cognition about cognitive phenomena (Flavell, 1979), encompasses an individual's awareness of their own thought processes as well as their ability to monitor and evaluate the accuracy or adequacy of their progress. This reflective capacity allows solvers to assess their strategies and outcomes, ensuring that errors are identified, and adjustments are made when necessary.

Similarly, the Semantic Congruence Model by Gros et al. (2020) also outlines key processes involved in problem-solving. The first phase, initial encoding, involves abstracting the problem statement into an interpreted structure shaped by mathematical semantics (knowledge of math concepts) and world semantics (real-world knowledge), which influence how relations between entities are represented. In the specification phase, this structure is refined into a solving algorithm, although this is only possible with a deep structure that captures all critical relations. When initial encoding fails, recoding may reinterpret the problem, relying on mathematical semantics to create a new representation closer to the deep structure. Both models, Mayer’s and Gros’s, underline the importance of forming an accurate mental representation of the problem.

Given that AWPs require solvers to process both linguistic and numerical information, reading comprehension (Boonen et al., 2013; Fuchs et al., 2018) and arithmetic skills (Fuchs et al., 2006, 2012) have been long studied and shown to play a critical role. However, it is noteworthy that even students who demonstrate strong linguistic and arithmetic abilities frequently encounter challenges when tackling AWPs (see Daroczy et al., 2015). This observation leads to two significant conclusions: first, the primary challenge in solving AWPs may not reside in understanding the text of the problems or executing the arithmetic operations, but rather in the integration of relevant information to construct an accurate mental representation of the problem (Lucangeli et al., 1998; Montague & Applegate, 1993; Passolunghi et al., 1999; Yip et al., 2020). For instance, a student may understand the wording of a problem and have the mathematical skills to solve it, yet still struggle if they cannot accurately represent the problems’ situational structure and the relationships between its elements. In this respect, research comparing high and low achievers consistently indicates that these groups differ significantly in their ability to construct mental models (Hegarty et al., 1995; Mayer & Hegarty, 1996; Passolunghi et al., 1999; Yip et al., 2020). Secondly, this suggests that, in addition to reading comprehension and arithmetic skills, other domain-general cognitive abilities are essential for successful AWP-solving, particularly in the realm of problem representation. Among these abilities, the literature highlights the importance of fluid intelligence (Mori & Okamoto, 2017; Swanson & Beebe-Frankenberger, 2004), working memory (Soltanlou et al., 2015), and executive functions (Passolunghi & Siegel, 2001; Swanson et al., 1993).

Fluid intelligence

Fluid intelligence is defined as the use of deliberate mental operations to solve novel problems—tasks that cannot be performed as a function of simple memorization or routine (Primi et al., 2010). Such mental operations comprise cognitive processes related to inductive and deductive reasoning, as well as quantitative reasoning (Sternberg & Ben-Zeev, 1996). Extensive research has established fluid intelligence as a key predictor of AWP-solving ability in primary school children. For instance, Lee et al. (2004) demonstrated that 10-year-old children with higher scores in intelligence, reading skills, and vocabulary were also more successful at solving AWPs. Additionally, a meta-analysis by Peng et al. (2019) revealed that the relationship between fluid intelligence and mathematics tends to strengthen with age, with fluid intelligence showing stronger associations with complex mathematical skills than with basic mathematical abilities.

Working Memory

Working memory is defined as a limited capacity cognitive system that enables individuals to hold and simultaneously manipulate information over brief periods of time (Baddeley & Hitch, 1974). According to the classical multicomponent model (Baddeley, 2000; Baddeley & Hitch, 1974), working memory is distinguished by: (1) verbal subsystem, which is responsible for the temporary storage of verbal information, such as words and numbers; (2) visuo-spatial subsystem, which allows the temporary storage of visual and spatial information, such as colors, figures and positions in space; and (3) the central executive, which is involved in regulating, manipulating, and processing the stored verbal and visuo-spatial information.

Extensive research has shown a robust relationship between children's working memory capacity and their ability to solve AWPs effectively, both in children and adults (see the review by Peng & Fuchs, 2016). Specifically, working memory serves as a fundamental resource for several cognitive processes involved in AWP-solving, including reading comprehension, the integration of linguistic and numerical information into a coherent problem model, planning and maintaining subgoals, and executing arithmetic operations (Jaffe & Bolger, 2023). In this respect, studies suggest that low levels of working memory capacity can pose a risk factor for the development of mathematical difficulties (Peng et al., 2016; Swanson & Beebe-Frankenberger, 2004). Children who struggle with math often exhibit impaired working memory (Geary, 2010; Passolunghi et al., 2010), underscoring the critical role of working memory in math and problem-solving. More specifically, studies show that one component of working memory, the central executive system, is particularly crucial for solving AWPs (Andersson, 2007; Lee et al., 2004; Swanson, 2006, 2004; Swanson & Sachse-Lee, 2001).

Executive Functions

According to Miyake et al. (2000), the central executive system within Baddeley's WM model is related to three core executive functions: inhibition, updating, and shifting (see also Miyake & Friedman, 2012). Research has highlighted especially the importance of inhibition and updating in math learning (Passolunghi & Costa, 2019; Yeniad et al., 2013).

Inhibition is defined as the ability to suppress irrelevant information and inhibit dominant or prepotent responses (Miyake & Friedman, 2012). Inhibition has been widely linked to mathematical performance (Bull & Scerif, 2001; Khng & Lee, 2009; Swanson & Fung, 2016; Usai et al., 2018), and many studies suggest that it is a core process in solving AWPs. Effective AWP-solving requires processing a great number of linguistic and numerical information while inhibiting all the non-target information in order to retain in memory only the solution-relevant elements (Passolunghi et al., 1999) Consistent with these findings, Passolunghi and Siegel (2001) observed that children with poor word problem-solving skills exhibited an impairment in inhibitory processes. These studies indicate that children with poor problem-solving ability tend to have difficulty in effectively suppressing irrelevant information, which may potentially result in memory overload and an inadequate problem representation, consequently resulting in a higher frequency of errors.

Updating requires attributing different levels of activation to the items presented and maintaining a restricted set of elements activated continuously (Miyake & Friedman, 2012). In other words, updating represents the ability to replace outdated and irrelevant information with new and relevant information. Several studies have emphasized the importance of updating as a key cognitive process in AWP-solving (Blessing & Ross, 1996; Hammerstein et al., 2019; Iglesias-Sarmiento et al., 2015; Kotsopoulos & Lee, 2012; Lee et al., 2018). Passolunghi and Pazzaglia (2005) demonstrated that children proficient in AWPs also exhibit stronger updating abilities. Agostino et al. (2010) investigated the extent to which inhibition, updating, shifting, and mental-attentional capacity (M-capacity) contribute to children's ability to solve multiplication word problems. Through structural equation modeling, they found that updating played a more important role than age in predicting performance on multi-step problems (problems that require more than one operation to be solved), whereas both age and updating were equally important predictors of one-step problems. These findings suggest that updating is particularly important in solving AWPs that require a more complex problem representation. Mori and Okamoto (2017) revealed that individuals with strong updating abilities construct a model of the problem that includes only task-relevant information, whereas those with weaker updating skills incorporate extraneous information as well. This supports the idea that updating is essential for activating only necessary information to build an accurate problem model.

In summary, while existing research has identified the importance of reading comprehension and arithmetic skills in AWP-solving, there remains a significant gap in understanding how domain-general cognitive abilities contribute to the problem-solving process. Specifically, the role of these abilities in supporting the integration of information into a coherent problem representation, which is the core component of AWP-solving (Mayer & Hegarty, 1996), warrants further investigation.

1.2.2 Emotional-Motivational Factors

A substantial body of research has demonstrated that above and beyond the influence of cognitive abilities, emotional-motivational factors significantly contribute to math performance (Cargnelutti et al., 2017; Passolunghi et al., 2019; Vukovic et al., 2013). One of the most widely studied constructs in this domain is math anxiety, which is commonly defined as “a feeling of tension and anxiety that interferes with the manipulation of numbers and the solving of math problems in ordinary life and academic situations” (Richardson & Suinn, 1972, p. 551). Extensive research shows a moderate negative relationship between MA and overall math performance (see meta-analyses by Caviola et al., 2022; Namkung et al., 2019; Zhang et al., 2019). Beyond impairing math performance, MA can lead students to develop math-avoidant behaviors (Ashcraft & Krause, 2007; Pizzie & Kraemer, 2017), reinforcing negative attitudes towards mathematics, and perpetuating a cycle of underachievement. MA is highly prevalent across populations (Ramirez et al., 2018), with some evidence suggesting that it emerges as early as primary school (e.g., Ramirez et al., 2016; Szczygieł et al., 2024; Szczygieł & Pieronkiewicz, 2022; Tomasetto et al., 2021), making it a critical area for educational concern and intervention.

Gender differences in MA have also been widely documented, with several studies indicating that females tend to report higher levels of MA than males, despite showing similar levels of math achievement (Devine et al., 2012; Hill et al., 2016; Goetz et al., 2013). Research suggests that the higher prevalence of MA among females may stem from a combination of factors, such as gender stereotypes about math ability (Justicia-Galiano et al., 2023; Passolunghi et al., 2014) and greater emotional sensitivity to evaluative pressure in academic contexts (Else-Quest et al., 2010). Gender differences in MA persist into adolescence and adulthood, potentially influencing long-term academic and career choices related to mathematics (Ganley & Lubienski, 2016; Stoet et al., 2016). However, the presence of gender differences in MA among school-aged children remains contentious, with mixed findings reported in the literature (e.g., Dowker et al., 2012; Harari et al., 2013; Hill et al., 2016; Szczygieł, 2019; Vanbinst et al., 2020).

Math Anxiety and AWP-Solving Performance

Despite the considerable body of research on MA and its impact on math learning, there remain significant gaps in our understanding of the specific role that MA plays in AWP-solving. Most studies on MA have focused on basic math skills, such as calculation, or on overall math performance (Commodari & La Rosa, 2021; Cuder et al., 2023; Harari et al., 2013; Hill et al., 2016; Korem et al., 2022; Lee & Cho, 2018; Passolunghi et al., 2016; Soltanlou et al., 2019; Sorvo et al., 2017; Živković et al., 2023), with only a few investigating its specific impact on AWP-solving (Lai et al., 2015; Passolunghi et al., 2019; Ramirez et al., 2013, 2016). Notably, some recent studies have suggested that the relationship between MA and math performance differs based on the aspect of mathematics under evaluation (Caviola et al., 2022). In particular, MA seems to strongly impair the accuracy of mathematical tasks that involve complex cognitive skills (Wu et al., 2012), whereas the association is less pronounced when assessing basic computational skills (Harari et al., 2013; Wu et al., 2012). Since AWP-solving is a cognitively demanding task that requires students not only to process numerical information but also to comprehend and integrate linguistic information, it is plausible that the relationship between MA and AWP-solving could differ from the relationship with other types of mathematical tasks. Therefore, more studies are needed to fully understand the relationship between MA and AWP-solving.

Math Anxiety and Math Performance: Underlying Mechanisms

The mechanisms through which MA negatively affects math performance, and particularly AWP-solving, remain unclear especially when considering primary school students (Zhang et al., 2019). According to affective models, such as the Metacognition, Affect, and Self-Regulation Learning (MASRL) model (Efklides, 2011), emotional factors like anxiety are thought to influence metacognitive and cognitive processes during task execution. More specifically, anxiety may influence metacognitive experiences, such as increasing perceptions of task difficulty (Efklides, 2011; Efklides & Petkaki, 2005), which serve as critical input for self-regulation, strategy use, effort, and state emotions. When tasks are perceived as highly difficult, students may become disengaged, leading to lower performance (Nuutila et al., 2021). However, this hypothesis has yet to be investigated in the context of MA and AWP-solving.

In terms of MA's influence on cognitive processes, one well-established theory is that MA impairs performance by reducing the working memory capacity, which is essential for solving math tasks (e.g., Ramirez et al., 2016; Soltanlou et al., 2019). According to the Processing Efficiency Theory (Eysenck & Calvo, 1992), anxiety-related worries interfere with working memory resources (Ashcraft & Kirk, 2001; Owens et al., 2012), leading to lower accuracy and/or speed in the execution of tasks that require the involvement of working memory resources (e.g., Justicia-Galiano et al., 2017; Pellizzoni et al., 2022; Ramirez et al., 2016; Soltanlou et al., 2019; Vukovic et al., 2013). This theory has been largely supported, particularly in studies involving adults and older students (Buelow & Frakey, 2013; Ganley & Vasilyeva, 2014) and utilizing simpler math tasks (Pellizzoni et al., 2022), as demonstrated in the meta-analysis by Finell et al. (2022). However, its applicability is less established in primary school children engaged in AWP-solving tasks.

Math Anxiety and Ego-Resiliency

Some studies have suggested the presence of protective factors that may buffer against the development or effects of MA, one of which is ego-resiliency. Ego-resiliency is a temperamental trait defined as a pattern of individual features such as general resourcefulness, strength of character, and flexibility of functioning, that enables individuals to recover quickly from difficulties and day-to-day challenges (Block & Block, 1980). According to the theoretical conceptualization by Block and Block's (1980, 1996), ego-resilient individuals sustain a robust adaptational system and exhibit stronger emotional regulation, which allows them to manage negative emotions effectively in stressful situations and reduces the risk of anxiety (Eisenberg et al., 2011; Lee & Johnston-Wilder, 2017; Martin & Marsh, 2006). Supporting this theoretical perspective, previous research showed a negative association between ego-resiliency and anxiety (Donolato et al., 2019, 2020; Huey & Weisz, 1997; Putwain et al., 2013). For instance, Mammarella et al. (2018) conducted a latent profile analysis and found that primary school children with a low anxiety risk profile (general anxiety, test anxiety and math anxiety) scored higher on resilience than those at higher risk for anxiety. These findings suggest that ego-resiliency could act as a protective factor in the development of various forms of anxiety.

During math learning, students frequently experience some level of challenge, adversity or pressure, such as evaluative stress, scarce performance, demanding tasks, and difficulties in understanding concepts (Ashcraft et al., 2007; Ashcraft & Ridley, 2005), that promote feelings of anxiety. According to the definition given above, ego-resiliency could be a relevant personal resource for managing school challenges and emotional difficulties during math learning (Alessandri et al., 2017). However, research has yet to consider how the interplay between MA and temperamental personal assets (e.g., ego-resiliency) influences AWP-solving performance concurrently, especially in school-aged children who are in the process of learning mathematics. Addressing these gaps is essential for developing more comprehensive models of how emotional-motivational factors influence AWP-solving and for designing targeted interventions to support students who struggle with both anxiety and mathematical problem-solving.

1.3 Interventions to Enhance AWP-Solving Ability

Considering the significant difficulties that primary school children face in solving AWPs, a range of instructional practices and interventions have been developed over recent decades to improve AWP-solving ability. Intervention studies among primary school children, particularly those with or at risk for mathematical learning disabilities, have predominantly focused on enhancing cognitive components involved in problem-solving (see meta-analyses by Kong et al., 2021; Lein et al., 2020; Zheng et al., 2013), such as reading comprehension (e.g., Kurshumlia & Vula, 2019; Moran et al., 2014), problem representation (e.g., Fuchs et al., 2003; Jitendra et al., 2007), planning (e.g., Schukajlow & Krug, 2013), and metacognition (e.g., Lee et al., 2014; Montague, 2008). While all these interventions appear to be effective in enhancing AWP-solving abilities, meta-analytic findings demonstrate that those focused on improving and supporting children's capacity to accurately represent problems—specifically, the process of constructing mental models—are particularly effective in boosting AWP-solving performance (Kong et al., 2021; Lein et al., 2020; Myers et al., 2022), since they tackle the heart of AWP-solving (de Koning et al., 2022). One such cognitive strategy is the model method, also known as the bar diagram method (Ng & Lee, 2009). This instructional approach encourages students to visually represent the situational model of AWPs using bar diagrams. By constructing a clear visual representation, students can reflect, integrate the information, understand the relationships between different elements of the problem, more easily grasp the problem's mathematical structure, and apply appropriate arithmetic operations (de Koning et al., 2022). This approach is also believed to decrease cognitive load in working memory, since children are instructed to draw the information instead of manipulating them in memory (Fuchs et al., 2021).

On the other hand, emotional-motivational factors, such as MA, have been largely overlooked in AWP-solving intervention studies. Since MA negatively impacts math learning (Caviola et al., 2022), it would be important to explore whether interventions reducing MA may also improve children's AWP-solving performance (Passolunghi et al., 2020). Interventions designed to address MA in primary school children typically fall into two broad categories: (1) mathematical intervention approach and (2) cognitive-behavioral intervention approach (Balt et al., 2022; Sammallahti et al., 2023; Shakmaeva, 2022). While mathematical intervention approach aims to reduce MA indirectly by strengthening math skills, cognitive-behavioral intervention approach directly targets anxiety-related cognitions (e.g., negative thoughts and rumination about one's abilities or fear of failure) with techniques such as reappraisal, growth mindset training, and coping strategies (Balt et al., 2022). Reappraisal involves reshaping negative thoughts into positive or constructive perspectives (Hofmann et al., 2009), growth mindset training promotes the belief that abilities can improve through effort (Dweck, 2006), and coping strategies equip individuals with tools to manage anxiety and stress effectively, enhancing their resilience in the face of academic challenges (Hines et al., 2016; Passolunghi et al., 2020). Some studies have evaluated the effects of cognitive-behavioral interventions in reducing MA and improving general math performance, however the results remain mixed. While some studies with developmental samples have found that these interventions successfully reduce MA and improve math achievement (Kim et al., 2017; Ruff & Boes, 2014; Sheffield & Hunt, 2006; Singh, 2016), others suggest that while cognitive-behavioral approach alleviates MA, it does not necessarily lead to improved math performance (Passolunghi et al., 2020; Samuel et al., 2022).

To date, no study has evaluated the effects of interventions targeting MA in efforts to enhance primary school children's AWP-solving skills. Thus, it remains unclear whether reducing MA alone is sufficient to improve AWP-solving performance and whether this improvement is comparable to the improvement gained by cognitive interventions. Investigating the impact of emotional-motivational interventions and comparing them with cognitive-focused approaches could provide valuable guidance for designing effective instructional practices. Additionally, it could shed light on whether emotional-motivational factors are causal contributors to AWP-solving difficulties.

1.4 Overview of the Present Dissertation

The primary goal of the present doctoral dissertation was to broaden our understanding of the individual factors contributing to difficulties in AWP-solving among primary school children, and to develop interventions aimed at improving their problem-solving abilities. Unlike existing theoretical models of AWP-solving, which predominantly emphasize cognitive abilities as the main source of individual differences (Daroczy et al., 2015), this research adopted a holistic perspective. It explored both cognitive and emotional-motivational predictors of AWP-solving performance, examining their interactions and comparing the effectiveness of cognitive-based versus emotional-motivational interventions.

Study 1 (Chapter 2) focused on cognitive factors involved in AWP-solving. Specifically, the study explored the role of executive functions—inhibition and updating—alongside fluid intelligence and reading comprehension in predicting AWP-solving ability of fourth and fifth graders. The study addressed a critical gap in the literature by investigating how these cognitive processes contribute to the construction of a mental representation. To explore this, we administered two types of AWPs: consistent and inconsistent problems. In consistent problems, the relational term (e.g., *more than*) aligns semantically with the required arithmetic operation (e.g., addition), allowing for a relatively straightforward solution that does not need to construct a mental model of the problem. In contrast, inconsistent problems include a relational term (e.g., *more than*) that does not semantically match the correct arithmetic operation (e.g., subtraction), thereby requiring a more complex cognitive approach to construct an accurate mental representation of the problem situation. We hypothesized that inconsistent problems would be more challenging than consistent ones, as they demand the construction of a situational model. Furthermore, we expected that the construction of a mental model for inconsistent AWPs would depend on cognitive control processes, such as fluid intelligence, inhibition, and updating, which we predicted would have both direct and mediated effects on performance, with reading comprehension serving as a mediator.

Study 2 (Chapter 3) aimed to broaden our understanding on the role of emotional-motivational factors in AWP-solving performance. In particular, the study explored the relationship between MA, metacognitive experiences of perceived task difficulty, and AWP-solving proficiency in a sample of fifth graders. This investigation was based on the MASRL model (Efklides, 2011), which assumes that affective factors, such as anxiety, can influence metacognitive experiences of task difficulty (Efklides, & Petkaki, 2005), which, in turn, lead to lower performance (Nuutila et al., 2021). In accordance with the MASRL model, we hypothesized that MA would be negatively related to AWP-solving performance and that this relationship would be partly mediated by metacognitive experiences of task difficulty. This exploration aimed to provide novel theoretical insights into the factors contributing to difficulties in AWP-solving and to clarify the mechanisms through which MA affects AWP-solving performance. Furthermore, to address the inconsistent findings in the literature concerning the role of gender in MA among primary school students, this study also aimed to investigate potential gender differences in these constructs.

To further explore the role of MA in AWP-solving, Study 3 (Chapter 4) adopted a holistic approach and examined the interplay between MA, cognitive factors (i.e., working memory), and temperamental factors (i.e., ego-resiliency) on math performance in children from grades 3 to 5. According to the well-known Processing Efficiency Theory (Eysenck & Calvo, 1992), anxiety would interfere with cognitive resources of working memory, leading to poor math achievement. On the other hand, research demonstrates that the temperamental trait of ego-resiliency may act as a protective factor, with ego-resilient pupils being better at adapting to stressful situations and managing emotions and worries, exhibiting therefore lower anxiety levels (Donolato et al., 2019; Mammarella et al., 2018; Putwain et al., 2013). We therefore expected ego-resiliency to be negatively related to MA. MA would then have both a direct and an indirect negative effect through WM on math performance. In order to investigate the possible different contribution of temperamental, emotional and cognitive factors on different tasks, our study aimed to further previous research by taking into consideration two math skills, i.e. arithmetic skills and AWP-solving.

Finally, Study 4 (Chapter 5) aimed to contribute to the literature on AWP-solving intervention research. Existing research has shown that both cognitive and emotional-motivational factors predict problem-solving performance (Lai et al., 2015; Passolunghi et al., 2019). Despite these findings, most existing AWP-solving interventions focus primarily on cognitive strategies. The study addresses this gap by comparing the effects of two novel, non-intensive interventions to promote AWP-solving ability in typically developing third- to fifth-graders: one intervention targeting the cognitive factors of problem-solving and the other focusing on emotion-motivational factors, specifically MA. This study targeted typically developing children, a population often overlooked in favor of those with math learning disabilities (MLD) or those at risk for MLD. While it is crucial to explore interventions for children with MLD, it is equally important to identify effective strategies for typically developing children, who also exhibit a significant percentage of below-average performance in AWP-solving tasks (INVALSI, 2022). Moreover, the interventions were designed to be non-intensive, collective, and easily implemented in classroom settings, in contrast with the more common intensive, small-group formats used in previous studies (e.g., Fuchs et al., 2021; Jitendra et al., 2007; Powell et al., 2023). As highlighted by the meta-analysis by Kong et al. (2021), there is a need to develop and implement instructions for all students before utilizing additional resources for more intensive and individualized programs. In this study, children were randomly assigned to one of three conditions: cognitive intervention, emotional-motivational intervention, or a business-as-usual control group. Pre- and post-intervention assessments measured AWP-solving ability, problem representation skills, and MA. We hypothesized that the cognitive intervention would outperform the control group in AWP-solving, whereas no specific hypothesis was made for the emotional-motivational intervention given the mixed results in literature (Balt et al., 2022; Sammallahti et al., 2023). Additionally, we expected the cognitive intervention to outperform both the control and emotional-motivational conditions in problem representation (Ng & Lee, 2009), while the cognitive intervention and emotional-motivational interventions were hypothesized to be more effective in reducing MA compared to the control group (Passolunghi et al., 2020; Sammallahti et al., 2023).

In the final chapter (Chapter 6), the main findings from all four studies are summarized, along with a discussion of their theoretical and practical implications.

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2. STUDY ONE

The Role of Updating, Inhibition, Fluid Intelligence, and Reading Comprehension in Explaining Differences in Arithmetic Word Problem-Solving Performance[1]

Abstract

Children's ability to solve arithmetic word problems (AWPs) is a key predictor of their academic success and future employment opportunities in adulthood. Central to solving AWPs is problem representation—the process of constructing a mental model of the problem's situation. This study investigated the role of cognitive abilities (reading comprehension, fluid intelligence, inhibition, and updating processes) in children's performance on AWPs that vary in their demands for problem representation. 182 fourth and fifth graders were administered an AWP-solving task and other tasks assessing fluid intelligence, reading comprehension, inhibition, and updating. The AWP-solving task included problems with a relational term consistent or inconsistent with the required arithmetic operation. In consistent problems children can use a straightforward keyword strategy, whereas in inconsistent problems children must construct a mental model of the problem. The results revealed that consistent AWPs were easier than inconsistent ones. Path analyses showed that reading comprehension was the most important predictor of overall AWP performance. Fluid intelligence had both direct and indirect effects, mediated by reading comprehension, on the overall AWP performance. Moreover, both executive functions—updating and inhibition—had a distinct and significant effect on overall AWP accuracy. When consistent and inconsistent problems were analyzed separately, the findings revealed a differential role for executive functions: efficiency in solving consistent problems was related to only inhibition, whereas in inconsistent problems was related to inhibition and updating. These findings underscore the importance of domain-general cognitive factors in problem representation.

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[1] Adapted from Passolunghi, M. C., De Blas, G. D., Carretti, B., Gomez-Veiga, I., Doz, E., & Garcia-Madruga, J. A. (2022). The role of working memory updating, inhibition, fluid intelligence, and reading comprehension in explaining differences between consistent and inconsistent arithmetic word-problem-solving performance. *Journal of Experimental Child Psychology*, *224*, 105512. https://doi.org/10.1016/j.jecp.2022.105512

2.1 Introduction

Mathematical knowledge is a fundamental aspect of contemporary human cultures and societies, and—alongside reading and writing—it constitutes one of the core components of a literate mind. As a result, arithmetic word problems (AWPs) hold a significant place in school curricula. Notably, children's ability to solve AWPs is a strong predictor of their overall academic success (Duque de Blas et al., 2021) and their future employment and earnings in adulthood (Gross et al., 2009; Murnane et al., 2001). Thus, gaining a deeper understanding of the difficulties students face when solving AWPs, as well as the cognitive factors underlying this skill, is essential for both educational progress and societal development. Moreover, it holds significant theoretical value for advancing our understanding of problem-solving abilities.

Solving an AWP requires individuals to integrate both linguistic and mathematical knowledge, in a process where understanding the problem is closely linked to finding the correct solution. This process goes beyond merely performing basic arithmetic operations (i.e., addition, subtraction, multiplication, and division); more critically, it requires selecting the appropriate operation. A crucial element in this process is constructing an accurate *problem representation*—that is, forming a mental model of the problem by accurately integrating the numerical and verbal information contained in the problem's narrative (De Corte et al., 1985; Lee et al., 2009).

While the importance of problem representation has been extensively demonstrated (e.g., Lucangeli et al., 1998; Hegarty et al., 1995; Passolunghi et al., 1999; Yip et al., 2020), less is known about the cognitive factors involved in constructing an effective problem representation. In the present study, we aimed to examine the role of key cognitive factors—including inhibition, updating, fluid intelligence, and reading comprehension—in predicting children's ability to solve AWPs, differing in whether they request to engage in constructing a problem representation or not.

2.1.1 Problem Representation in Consistent and Inconsistent AWPs

Problem representation in AWP-solving can be effectively revealed when comparing two types of problems: consistent and inconsistent AWPs (De Corte et al., 1985; Kintsch, 1998; Thevenot, 2010; Thevenot & Oakhill, 2005, 2006; Van der Schoot et al., 2009). These AWPs involve comparing two sets for a difference, often using a relational term to signal the comparison (Powell & Fuchs, 2018). In consistent AWPs, the relational term (e.g., more than) is semantically coherent or consistent with the arithmetic operation required to find the solution (e.g., addition). An example of consistent problem is: “At Walmart, a pair of Adidas sneakers costs €30. The same pair of sneakers costs €6 more at Decathlon. How much does a pair of Adidas sneakers cost at Decathlon?”. In inconsistent AWPs, the relational term (e.g., more than) is semantically incoherent with the arithmetic operation (i.e., subtraction). For instance: “At Walmart, a pair of Adidas sneakers costs €30. This is €6 more than the same pair of sneakers at Decathlon. How much does a pair of Adidas sneakers cost at Decathlon?”. While seemingly straightforward, inconsistent AWPs can be deceptively complex, demanding a deep understanding of the problem’s structure and an accurate mental representation of the situation. According to Kintsch and Greeno (1985), this representation has two levels: a first propositional level accounting for explicit information in the text and a situational model involving a complete integration of this information with the reader’s previous knowledge, including information about relations among quantities (Fuchs et al., 2021). It is only after constructing an integrated situational model that the reader realizes that the sneakers at Decathlon are less expensive than the sneakers at Walmart.

Many studies have examined the distinction between consistent and inconsistent AWPs, demonstrating that performance accuracy is significantly lower on inconsistent AWPs compared to consistent ones (Jarosz & Jaeger, 2019; Jiang et al., 2020; Lubin et al., 2013, 2016; Mayer & Hegarty, 1996; Pape, 2003). This phenomenon has been named *consistency effect* (Hegarty et al., 1995). More importantly, the most common mistake made in solving inconsistent AWPs are reverse errors—that is, mistakenly applying the operation suggested by the relational term in the text (Boote & Boote, 2018; Lewis & Mayer, 1987; Mayer & Hegarty, 1996; Shum & Chan, 2020; Stern, 1993; Verschaffel, 1994; Verschaffel et al., 1992).

The consistency effect has been explained by the fact that students can solve consistent problems based merely on a *direct translation strategy*, relying on a direct translation of the information in the text. They simply search for linguistic markers and keywords and associate *less* with subtraction and *more* with addition (Hegarty et al., 1995). In contrast, solving inconsistent AWPs requires a more sophisticated approach known as the *problem model strategy*. Here, students must build an integrated mental model of the situation described in the problem that accurately represents the relations between the sets rather than relying solely on linguistic cues (Thevenot, 2010; Thevenot, & Barrouillet, 2015). This translation requires the identification of the pronominal reference ‘that is’ as the indicator of the relation between the value of the first variable (e.g., the price of the sneakers at Walmart) and the second (e.g., the price of the sneakers at Decathlon). On the basis of the constructed mental model, problem solvers are then able to plan and execute the required arithmetic operations. It can be concluded that inconsistent AWPs are more complex, since they require to construct a situational model of the problem and therefore, they are suitable to measure the process of problem representation.

2.1.2 Cognitive Factors in AWP-Solving

Working Memory

Multiple processes are involved in solving AWPs. Problem solvers must read the problem, identify and retain relevant information, construct a mental model, plan the solution, and perform calculations based on this plan (Hegarty et al., 1995). All of these phases require working memory (WM) resources (Friso-van der Bos et al., 2013; Fung & Swanson, 2017; Kintsch, 1998). A large body of research has investigated the role of WM in problem-solving by referring to the well-known tripartite WM model introduced by Baddeley and Hitch (1974). Several studies have shown that one component of this model, the central executive system, is particularly crucial for solving AWPs (Andersson, 2007; Fuchs et al., 2010; Lee et al., 2004; Swanson, 2006; Swanson & Sachse-Lee, 2001). For instance, Swanson (2004) found that the central executive contributes significantly to AWP-solving accuracy, even after controlling for phonological processing ability, fluid intelligence, and reading comprehension.

Executive Functions

According to Miyake et al. (2000), the central executive system within Baddeley's WM model is related to three core executive functions: inhibition, updating, and shifting (see also Miyake & Friedman, 2012). Inhibition refers to the ability to suppress dominant or prepotent responses. Updating is the ability to continuously replace outdated or irrelevant information, ensuring that only the pertinent elements are retained in WM. Shifting involves the ability to switch between strategies while managing multiple tasks or mental processes. Several studies have highlighted the role of the executive functions in AWP-solving, particularly emphasizing the importance of inhibition and updating, whereas just a few studies have investigated the role of shifting in mathematics performance, and the outcomes are rather mixed (Passolunghi & Costa, 2019; Yeniad et al., 2013). Therefore, this study focused specifically on the functions of inhibition and updating.

Inhibition has been widely linked to mathematical performance (Bull & Scerif, 2001; Khng & Lee, 2009; Swanson & Fung, 2016; Usai et al., 2018), and many studies suggest that it is a core process in solving AWPs (Lin, 2021; Passolunghi & Siegel, 2001). Effective AWP-solving requires processing a great number of linguistic and numerical information while inhibiting all the non-target and irrelevant information in order to retain in memory only the solution-relevant elements. Passolunghi et al. (1999) found that poor problem solvers struggled to recall relevant information and were more prone to making intrusion errors (this is, remembering irrelevant information), suggesting a difficulty in inhibitory process. Furthermore, Lubin et al. (2013, 2016) demonstrated that successful problem-solving of inconsistent AWPs relies on the ability to inhibit a prepotent response. They interpreted these results as that in inconsistent AWPs it is necessary to inhibit a misleading or overlearned strategy, such as "add if *more*, subtract if *less*". In other words, AWP-solving, and in particular situational problem representation in inconsistent AWPs, would demand the inhibition of a superficial propositional representation of the problem resulting from a direct translation approach, which would lead to reasoning errors (Hegarty et al., 1992; Hegarty et al., 1995; Mayer & Hegarty, 1996). Consistently, Lemaire and Lecacheur (2011) found that children with better inhibitory control made use of efficient strategies to solve arithmetic problems more frequently than children with lower levels of inhibitory control. Further evidence indicated that an increasing efficiency in solving inconsistent AWPs from childhood to adulthood is related to the gradual development of cognitive inhibitory control (Lubin et al., 2013, 2016).

Other studies have emphasized the importance of updating as a key cognitive process in AWP-solving (Blessing & Ross, 1996; Hammerstein et al., 2019; Iglesias-Sarmiento et al., 2015; Kotsopoulos & Lee, 2012; Lee et al., 2018). Passolunghi and Pazzaglia (2005) demonstrated that children proficient in AWPs also exhibit stronger updating abilities. Agostino et al. (2010) investigated the extent to which inhibition, updating, shifting, and mental-attentional capacity (M-capacity) contribute to children’s ability to solve multiplication word problems. Through structural equation modeling, they found that updating played a more important role than age in predicting performance on multi-step problems (problems that require more than one operation to be solved), whereas both age and updating were equally important predictors of one-step problems. These findings indicate that updating is particularly important in solving more complex AWPs. Mori and Okamoto (2016) suggested that updating is a central executive function necessary for efficient integration processes—similar to what Kintsch and Greeno (1985) argued—where verbal statements are translated into a situational representation to solve a problem. Their findings revealed that individuals with strong updating abilities construct a model of the problem that includes only task-relevant information, whereas those with weaker updating skills incorporate extraneous information as well. This supports the idea that updating is essential for activating only necessary information to build an accurate problem model. An updating failure would produce errors in the integration process, resulting in an inappropriate model and a consequently incorrect solution to the problem (see Kotsopoulos & Lee, 2012; Re et al., 2016).

Fluid Intelligence

Another important domain-general cognitive factor in relation to AWP-solving is fluid intelligence. Fluid intelligence comprises cognitive processes related to inductive and deductive reasoning, as well as quantitative reasoning (Sternberg & Ben-Zeev, 1996). Previous research has shown a strong correlation between fluid intelligence and executive functions (Conway et al. 2003; Duncan et al. 2008; Friedman et al., 2006; Kane & Engle 2002; Salthouse, 2005). Moreover, empirical evidence supports the role of fluid intelligence as a predictor of AWP-solving ability. For instance, Lee et al. (2004) demonstrated that 10-year-old children with higher scores in intelligence, reading skills, and vocabulary were also more successful at solving AWPs. Fung and Swanson (2017) found that fluid intelligence had an indirect effect on AWP-solving in third graders, and that reading and calculation skills mediated the influence of the WM executive system on AWP-solving in children aged 6–10 years. Additionally, a meta-analysis by Peng et al. (2019) revealed that the relationship between fluid intelligence and mathematics tends to strengthen with age, with fluid intelligence showing stronger associations with complex mathematical skills than with basic mathematical abilities.

Reading Comprehension

A substantial body of correlational and longitudinal research highlights the crucial role of reading comprehension in AWP-solving (Boonen et al., 2016; Can, 2020; Fuchs et al., 2018; Pape, 2004; Swanson et al., 1993; Vilenius-Tuohimaa et al., 2008). Evidence shows that reading comprehension has a medium to large effect on AWP-solving performance (Boonen et al., 2013), making it a key factor in understanding individual differences in this task. Intervention studies further corroborate this link, demonstrating that improving reading comprehension skills leads to significant gains in students’ ability to solve AWPs (Kurshumlia & Vula, 2019). Reading comprehension would support the construction of a propositional representation, which involves understanding the linguistic components of the problem’s text, and the construction of a situational representation, which requires students to grasp the relationships between the problem’s elements (Boonen et al., 2013; De Corte et al., 1985). This understanding allows for the accurate integration of numerical and verbal information, resulting in more effective problem-solving strategies and solution planning.

Moreover, reading comprehension is closely related to domain-general cognitive abilities such as fluid intelligence and executive functions. Studies have demonstrated that reading comprehension partially mediates the relationship between reasoning and AWP-solving (Can, 2020; Fung & Swanson, 2017), as well as the relationship between executive processes and AWP-solving accuracy (Iglesias-Sarmiento et al., 2015; Passolunghi & Pazzaglia, 2005; Thevenot & Barrouillet, 2015).

2.1.3 The Present Study

The main objective of the study was to examine the role of executive functions (specifically inhibition and updating), fluid intelligence, and reading comprehension in predicting children's ability to solve AWPs differing in whether they request to build a situational representation (inconsistent problems) or not (consistent problems). As already mentioned, in consistent problems, there is a relational term that is semantically congruent with the correct arithmetic operation required by the problem. Children can use a direct translational strategy to solve these AWPs, therefore bypassing the construction of a situational mental model. In contrast, in inconsistent problems, the relational term is inconsistent with the required operation. Here, to correctly solve the problem the solver cannot use a direct strategy and must involve in the model method strategy, by constructing a situational problem model representing the adequate relations between the sets.

More specifically, our aims and hypotheses can be outlined as follows:

First, given that inconsistent AWPs require the construction of a situational model, we anticipated to replicate the consistency effect observed in previous studies (Hegarty et al., 1995; Lewis & Mayer, 1987; Pape, 2003), which predicts higher accuracy for consistent AWPs compared to inconsistent ones (Hypothesis 1).

Second, if the challenge in solving inconsistent versus consistent AWPs lies in constructing an appropriate situational mental representation, then we proposed that this difficulty would stem from the lexical inconsistency (i.e., easier when the relational term aligns with the required operation, and more difficult when it conflicts; see Lewis & Mayer, 1987), rather than other problem features, such as the number of arithmetic operations (i.e., easier when one operation is required and more difficult with two). To determine whether the difficulty in solving inconsistent versus consistent problems stems from lexical inconsistency, we manipulated the number of operations required by the problems. Thus, we included problems requiring one or two consistent operations, problems requiring one or two inconsistent operations, and mixed problems involving two operations—one consistent and one inconsistent. We expected that the effect of lexical inconsistency would outweigh the effect of the number of operations required (Hypothesis 2).

Lastly, we wanted to examine the role of inhibition, updating, fluid intelligence and reading comprehension in the construction of the situational representation of AWPs by comparing their roles in consistent and inconsistent AWPs. We expected the construction of the situational representation of inconsistent AWPs to require cognitive control processes, such as fluid intelligence, inhibition, and updating, which would have a direct and mediated effect by reading comprehension (Hypothesis 3; see Iglesias-Sarmiento et al., 2015; Passolunghi & Pazzaglia, 2005; Thevenot & Barrouillet, 2015).

2.2 Method

2.2.1 Participants

A total of 203 children, aged between 10 and 11 years, from fourth and fifth grades of primary schools in northeastern Italy participated in the study. From this initial sample, students with intellectual disabilities (*n* = 5), specific learning disabilities (*n* = 8), and those for whom Italian was a second language (*n* = 8) were excluded. This exclusion resulted in a final sample of 182 participants (M_{age}= 10.6 years), comprising 95 females. The socio-economic status of the sample was primarily middle class, established on the basis of school records. The arithmetic abilities of the sample, as assessed by standardized testing, were consistent with the average levels expected for their grade. For sample size estimation, an a priori power analysis was conducted. Results indicated that the minimum sample size needed to achieve power = .80 for detecting a medium effect for the hypothesized mediation, at a significance criterion of $\alpha = .05$, was N = 174. Thus, our sample size is adequate.

The study obtained approval by the ethical committee of the University of Trieste and was carried out in compliance with the Declaration of Helsinki and the ethical guidelines of the Italian Association of Psychology. Written informed parental consent was obtained before assessing the students and all children participated voluntarily.

2.2.2 Measures

Arithmetic Word Problem-Solving

The task comprises 12 different compare problems. Based on the relational term used (either “more than” or “less than”), the problems were divided into two parallel versions, referred to as the *more* and *less* versions (see Table 2.1). The problems varied in lexical consistency (consistent, inconsistent, or mixed) and the number of operations required (one or two operations). In terms of lexical consistency, each version included: two consistent problems, where the relational term “more than” or “less than” is consistent with the operation required by the problem (addition and subtraction, respectively); two inconsistent problems, where the relational term “more than” or “less than” is inconsistent with the operation required by the problem (subtraction and addition, respectively); and two mixed problems, featuring both one consistent and one inconsistent relational term. One mixed problem presented the consistent term first followed by the inconsistent (consistent-then-inconsistent [C-I]), while the other did the opposite (inconsistent-then-consistent [I-C]). Regarding the number of operations, each version included: two problems (one consistent and one inconsistent) requiring a single arithmetic operation, and four problems (one consistent, one inconsistent, and both mixed problems) requiring two operations. Table 1 outlines the six different problems presented in each version. All problems were controlled for numerical complexity, sentence length, vocabulary, and syntactic structure. The average readability, measured using the Gulpease index (see Dell'Orletta et al., 2011), was above 55 for all problems, confirming their suitability for primary school children (see Tonelli et al., 2012). The AWPs were similar to those typically assigned to students in the relevant school grades. To minimize participant fatigue, each version of the AWP-solving task was administered in separate sessions on different days. Half of the participants completed the *more* version in the first session and the *less* version in the second, while the other half completed the versions in reverse order. For each correct operation, participants received 1 point. We then calculated five dependent variables: performance on consistent problems (AWP CON), performance on inconsistent problems (AWP INC), performance on mixed problems with consistent-then-inconsistent operation (AWP C-I), mixed problems with inconsistent-then-consistent operation (AWP I-C), and overall performance on all problems (AWP TOT). In this sample, the task demonstrated a Cronbach's α of .77.

Table 2.1

Different Types of AWPs Tested

Relational term	**AWP type**	**Number of operations**
More version	Consistent	1
	Inconsistent	1
	Consistent-Consistent	2
	Inconsistent-Consistent	2
	Consistent-Inconsistent	2
	Inconsistent-Inconsistent	2
Less version	Consistent	1
	Inconsistent	1
	Consistent-Consistent	2
	Inconsistent-Consistent	2
	Consistent-Inconsistent	2
	Inconsistent-Inconsistent	2

Reading Comprehension

Reading comprehension was assessed with two expository texts appropriate for fourth and fifth graders, drawn from the standardized Italian battery for the assessment of reading ability (Cornoldi et al., 2017). Participants were instructed to read the texts silently and then respond to 12 multiple-choice questions, with the text remaining accessible during the answering process. Cronbach's α was .69 for Grades 4 and .71 for Grade 5.

Fluid Intelligence

To assess fluid intelligence, we administered Scale 2, Form A, of the *Cattell Culture Fair Intelligence Test* (Cattell & Cattell, 1963). This measure consists of four reasoning subtests involving visuospatial material, each with a time limit of 2.5 to 4 minutes. For example, the "Matrices" subtest presents participants with 12 incomplete matrices consisting of 4 to 9 cells that contain abstract figures and shapes. Participants are required to complete each matrix by selecting the correct option from six possible choices. The final score was calculated as the sum of correct responses, with a maximum score of 36. The test-retest reliability coefficients provided in the test manual are .84 for fourth graders and .80 for fifth graders.

Updating

To evaluate children's updating skills, we used the updating task from Carretti et al. (2014), which comprises six lists of eight nouns each. The experimenter read each list aloud, and participants were instructed to recall the three smallest items from each list in the same order as they were originally presented. All words are highly familiar to the children and represented objects are easy to compare in terms of size. The dependent variable was the number of correctly recalled words, with a maximum possible score of 18. Cronbach's α for this task was .68.

Prepotent Response Inhibition

Inhibition was assessed using a pencil-and-paper version of the classic *Stroop color task*, as employed in previous research (Borella et al., 2010). The task comprised 15 trials, with each trial consisting of 20 stimuli presented on individual sheets of paper. In the first five trials (control-color condition), participants were required to name the colors of strings of capital "X"s. In the next five trials (incongruent condition), they were asked to name the ink color of words that were the names of colors, where the ink color and the word did not match. To successfully perform the incongruent condition, participants needed to inhibit the prepotent response prompted by reading the words and instead focus on the nondominant response prompted by the ink color. In the last five trials (congruent condition), participants had to name the color of the ink for words that were names of colors, but in this case, the ink color and words color were consistent. Response times and accuracy were recorded for each trial. An interference index was calculated as the difference in response times between the control-color condition and the incongruent condition: Higher interference scores indicated greater difficulty in inhibiting prepotent responses during the incongruent condition. The task demonstrated good reliability, with Cronbach's α values of 0.82 for the control-color condition, 0.73 for the incongruent condition, and 0.85 for the congruent condition.

2.2.3 Procedure

The study involved three sessions, two of which were administered collectively in classrooms and lasted approximately 45 minutes to 1 hour, and one administered individually. In the first session, participants completed the AWP-solving task (either the *more* or *less* version, balanced across participants) and the fluid intelligence test. The second session involved the administration of the remaining version of the AWP-solving task, along with the reading comprehension task. In the third session, the prepotent response inhibition task and the updating task were administered individually in a quiet room at school, taking approximately 20 minutes to complete.

2.3 Results

Table 2.2 presents the descriptive statistics for all measures included in the study. No statistically significant difference was found in accuracy between the two versions of the AWP-solving task (*more* and *less* version), $F(1, 181) = 3.506$, $p = .063$. Additionally, there was no statistically significant difference in AWP-solving performance between males and females, $F(1, 181) < .01$, $p = .958$.

Table 2.2

Descriptive Statistics for All Measures Included in the Study

Measure	***M***	***SD***
AWP CON	3.30	0.89
AWP INC	1.34	1.25
AWP I-C	0.73	0.80
AWP C-I	0.51	0.70
AWP total	5.87	2.79
Updating	10.47	2.39
Inhibition (time difference)	−87.01	33.87
Fluid intelligence	31.02	4.80
Reading comprehension	8.98	2.60

Note. AWP CON = consistent arithmetic word problems; AWP INC = inconsistent arithmetic word problems; AWP I-C = inconsistent-then-consistent arithmetic word problems; AWP C-I = consistent-then-inconsistent arithmetic word problems; AWP total = total arithmetic word problems.

First, the consistency effect was examined. As expected, a repeated-measures Analysis of Variance (ANOVA) revealed significant differences between consistent problems and inconsistent problems, $F(1, 181) = 415.08$, $MSE = 348.18$, $p < .01$, $\eta_p^2 = .69$. Additionally, a repeated-measures ANOVA showed significant differences in response accuracy between one-operation problems (*M*

= 2.70, *SD* = 0.95) and two-operation problems (*M* = 1.93, *SD* = 1.06), *F*(1, 181) = 102.43, *MSE* = 53.85, $p < .01$, $\eta_p^2 = .36$. It must be noted that lexical inconsistency had a larger effect than the number-of-operations.

When analyzing mixed problems, an effect of presentation order was observed, *F*(1, 181) = 12.97, *MSE* = 4.18, $p < .01$, $\eta_p^2 = .07$. Performance was significantly lower for problems with the inconsistent statement presented later (AWP C-I: *M* = 0.51, *SD* = 0.70) compared to those where the inconsistent statement was presented first (AWP I-C: *M* = 0.73; *SD* = 0.80). To investigate whether the differences in performance between AWP C-I and AWP I-C were attributable to WM overload, we conducted a one-way repeated-measures ANOVA with the updating measure as a covariate. After controlling for participants' updating abilities, the difference in difficulty between the two types of problems was no longer significant, *F*(1, 181) = 1.10, *MSE* = .36, $p = .295$. This result supports the assumption that updating is strongly related to AWP-solving ability and the ability to build a correct mental representation of the problem.

2.3.1 Correlations

Table 2.3 presents the correlations among the variables examined in this study. All measures demonstrated statistically significant correlations with one another. Notably, the strongest correlations emerged between reading comprehension and overall AWP score, between fluid intelligence and overall AWP score, as well as between updating ability and performance on inconsistent AWPs.

Table 2.3

Correlations Between Measures of Interest

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1. AWP I-C	1							
2. AWP C-I	.44**	1						
3. AWP CON	.26**	.26**	1					
4. AWP INC	.84**	.75**	.31**	1				
5. AWP total	.80**	.72**	.59**	.95**	1			
6. Updating	.20**	.27**	.18**	.27**	.28**	1		
7. Inhibition	.20**	.13*	.18**	.20**	.23**	.15*	1	
8. Fluid intelligence	.25**	.23**	.31**	.32**	.37**	.26**	.10	1
9. Reading comprehension	.27**	.30**	.30**	.36**	.40**	.18**	.02	.31**

Note. AWP I-C = inconsistent-then-consistent arithmetic word problem; AWP C-I = consistent-then-inconsistent arithmetic word problem; AWP CON = consistent arithmetic word problem; AWP INC = inconsistent arithmetic word problem; AWP total = total arithmetic word problem.

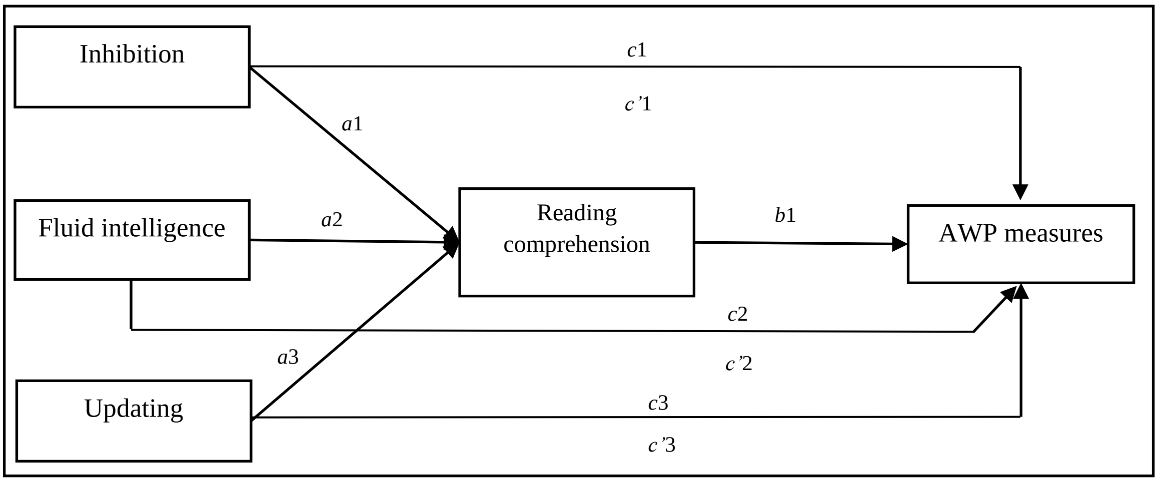
** $p < .01$; * $p < .05$ one-tail.

2.3.2 Predictors of AWP-Solving Ability

We conducted a series of path analyses using regression equations to clarify how the relationships between the cognitive variables explain performance in different types of AWPs. Path analyses included the three domain-general cognitive abilities (fluid intelligence, inhibition, and updating), one mediated measure (reading comprehension), and the outcome variables, which were analyzed separately: total AWP, AWP CON, AWP INC, AWP C-I, and AWP I-C. Figure 2.1 depicts the path model tested. All path models were computed using the same procedure but changing the predicted AWP outcome variable (total AWP, AWP CON, AWP INC, AWP C-I, or AWP I-C).

Figure 2.1

Path Model Tested in the Study



Note. AWP = arithmetic word problem.

General equations for different outcomes were as follows:

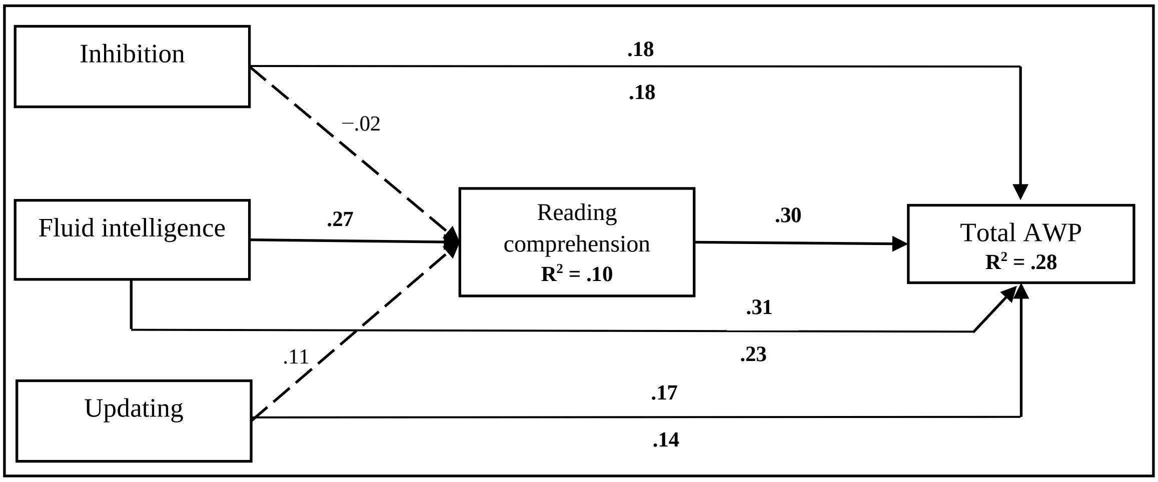
> Reading comprehension = $\beta 1 + \alpha 1$ (inhibition) + $e1 + \alpha 2$ (fluid intelligence) + $e2 + \alpha 3$ (updating) + $e3$
>
> AWP outcome = $\beta 2 + b1$ (reading) + $c'1$ (inhibition) + $c'2$ (fluid intelligence) + $c'3$ (updating) + $e4$

The first regression equation estimates the effects of inhibition, fluid intelligence, and updating on reading comprehension (i.e., the mediator). The second regression equation estimates the direct effects (*c'*) of inhibition, fluid intelligence, updating, and reading comprehension on the outcome variables (i.e., performance on AWPs). The indirect effects tested the effects of inhibition ($a1 \times b1$), fluid intelligence ($a2 \times b1$), and updating ($a3 \times b1$) on AWP-solving outcome measures through reading comprehension. Bootstrapping with 5,000 bootstrap samples was used to construct 95% confidence intervals for indirect effects. The direct effects (*c'*) of inhibition, fluid intelligence, and updating on AWP-solving outcome measures were independent of the indirect effects. Consequently, the direct effect of inhibition, fluid intelligence, and updating was the difference between the total effect (*c*) and the indirect effect. Total effect represents the overall effects of direct and indirect relations on AWP-outcome measures. Additionally, effect sizes (Cohen's f^2) are provided to indicate the overall impact of the predictors on each dependent variable: small effect $f^2 = 0.02$; medium effect $f^2 = 0.15$; large effect $f^2 = 0.35$.

Regarding the total AWP-solving performance (total AWP), results are presented in Figure 2.2 and Table 2.4. The overall model explained a total variance of $R^2 = .28$ ($f^2 = .38$). The effects of executive functions and fluid intelligence on the mediator (Paths *a*) were significant for only fluid intelligence ($B = .16$; $SE = .05$; $\beta = .27$; $p < .001$; 95% CI [0.07, 0.25]). This result was consistent across all AWP outcome models. The mediator, reading comprehension, had a significant effect on total AWP (Path *b*) ($B = .33$; $SE = .08$; $\beta = .30$; $p < .001$, 95% CI [0.17, 0.49]). The total effects of domain-general cognitive variables on total AWP (Paths *c*) were significant for inhibition ($B = .02$; $SE = .01$; $\beta = .18$; $p < .012$; 95% CI [0.01, 0.04]), fluid intelligence ($B = .19$; $SE = .05$; $\beta = .31$; $p < .001$; 95% CI [0.01, 0.28]) and updating ($B = .21$; $SE = .08$; $\beta = .17$; $p = .006$; 95% CI [0.05, 0.36]). When direct effects on total AWP (Paths *c'*) were considered, significant relationships were found for inhibition ($B = .02$; $SE = .01$; $\beta = .18$; $p = .007$; 95% CI [0.01, 0.04]), fluid intelligence ($B = .14$; $SE = .04$; $\beta = .23$; $p = .001$; 95% CI [0.05, 0.23]), and updating ($B = .17$; $SE = .08$; $\beta = .14$; $p < .027$; 95% CI [0.01, 0.32]). As for indirect effects of predictors on total AWP through the mediator variable (reading comprehension), only fluid intelligence was significant ($B = .05$; $SE = .02$; $\beta = .08$; $p = .012$; 95% CI [0.02, 0.10]) after bootstrapping.

Figure 2.2

Path Model for Total AWP-Solving Performance



Note. Lines in bold indicate statistically significant relationships, whereas dashed lines indicate statistically non-significant relationships. Total AWP = total arithmetic word problems.

Table 2.4

Direct, Indirect and Total Effects of Inhibition, Fluid Intelligence, Updating, and Reading Comprehension on Total AWP-Solving Performance

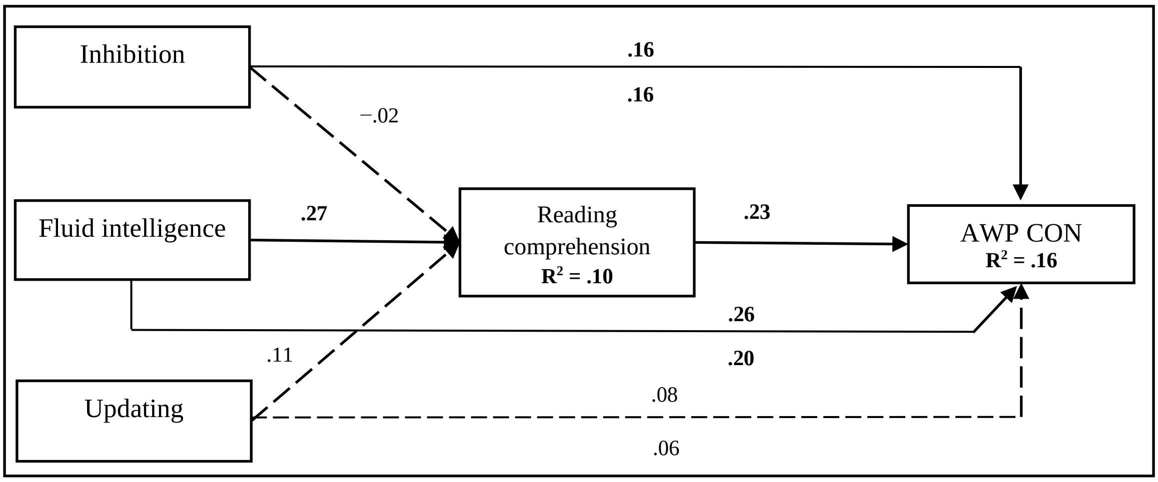
AWP Total	**Estimate**	**Std error**	**z-value**	**P(>|z|)**	**95% CI**	**Std.all**
Reading comprehension (b1)	0.328	0.082	4.018	0.000	[.17, .49]	0.304
Inhibition (c'1)	0.022	0.008	2.685	0.007	[.01, .04]	0.184
Fluid intelligence (c'2)	0.143	0.043	3.283	0.001	[.05, .23]	0.230
Updating (c'3)	0.170	0.077	2.209	0.027	[.01, .32]	0.140
Reading comprehension						
Inhibition (a1)	-0.002	0.008	-0.252	0.801	[-.02, .01]	-0.018
Fluid intelligence (a2)	0.155	0.048	3.262	0.001	[.07, .25]	0.271
Updating (a3)	0.121	0.075	1.609	0.108	[-.03, .27]	0.107
Indirect effects						
Inhibition → Reading → AWP Total (a1xb1)	-0.001	0.003	-0.244	0.807	[-.01, .01]	-0.006
Intelligence → Reading → AWP Total (a2xb1)	0.051	0.021	2.432	0.015	[.02, .10]	0.082
Updating → Reading → AWP Total (a3xb1)	0.040	0.026	1.502	0.133	[-.01, .10]	0.033
Total effects						
Inhibition → AWP Total (c1)	0.022	0.009	2.519	0.012	[.01, .04]	0.178
Intelligence → AWP Total (c2)	0.194	0.045	4.313	0.000	[.10, .28]	0.313
Updating → AWP Total (c3)	0.210	0.077	2.731	0.006	[.05, .36]	0.172

Note. AWP = arithmetic word problem.

Regarding the performance on consistent AWPs (AWP CON), results are presented in Figure 2.3 and Table 2.5. The total amount of variance explained by the whole model was $R^2 = .16$ ($f^2 = .19$). The effect of the mediator, reading comprehension, on AWP CON (Path *b*) was significant ($B = .08$; $SE = .03$; $\beta = .23$; $p = .006$, 95% CI [0.03, 0.14]). The total effects of executive functions and fluid intelligence on AWP CON (Paths *c*) were significant for inhibition ($B < .01$; $SE < .01$; $\beta = .16$; $p = .037$, 95% CI [0.00, 0.01]) and fluid intelligence ($B = .05$; $SE = .02$; $\beta = .26$; $p < .008$, 95% CI [0.02, 0.09]), but not for updating ($B = .03$; $SE = .03$; $\beta = .09$; $p = .22$). When direct effects on AWP CON (Paths *c'*) were considered, significant relationships were found for inhibition ($B < .01$; $SE < .01$; $\beta = .16$; $p = .027$; 95% CI [0.00, 0.01]) and fluid intelligence ($B = .04$; $SE = .02$; $\beta = .20$; $p = .039$; 95% CI [0.00, 0.08]), but not for updating ($B = .02$; $SE = .03$; $\beta = .06$; $p = .403$). As for indirect effects of predictors on AWP CON through the mediator variable (reading comprehension), only intelligence was significant ($B = .01$; $SE = .01$; $\beta = .06$; $p = .046$; 95% CI [0.00, 0.03]) after bootstrapping.

Figure 2.3

Path Model for Consistent AWP-Solving Performance



Note. Lines in bold indicate statistically significant relationships, whereas dashed lines indicate statistically non-significant relationships. AWP CON = consistent arithmetic word problems.

Table 2.5

Direct, Indirect and Total Effects of Inhibition, Fluid Intelligence, Updating, and Reading Comprehension on Consistent AWP-Solving Performance

Consistent AWP	Estimate	Std error	z-value	P(>|z|)	95% CI	Std.all
Reading comprehension (b1)	0.080	0.029	2.735	0.006	[.03, .14]	0.232
Inhibition (c'1)	0.006	0.003	2.208	0.027	[.00, .01]	0.161
Fluid intelligence (c'2)	0.039	0.019	2.065	0.039	[.00, .08]	0.198
Updating (c'3)	0.024	0.028	0.837	0.403	[-.04, .08]	0.060
Reading comprehension						
Inhibition (a1)	-0.002	0.008	-0.250	0.803	[-.02, .01]	-0.018
Fluid intelligence (a2)	0.155	0.047	3.284	0.001	[.07, .25]	0.271
Updating (a3)	0.121	0.075	1.601	0.109	[-.03, .27]	0.107
Indirect effects						
Inhibition → Reading → AWP CON (a1xb1)	-0.000	0.001	-0.238	0.812	[.00, .00]	-0.004
Intellig. → Reading → AWP CON (a2xb1)	0.012	0.006	1.997	0.046	[.00, .03]	0.063
Updating → Reading → AWP CON (a3xb1)	0.010	0.007	1.402	0.161	[.00, .03]	0.025
Total effects						
Inhibition → AWP CON (c1)	0.006	0.003	2.082	0.037	[.00, .01]	0.157
Intelligence → AWP CON (c2)	0.052	0.019	2.663	0.008	[.02, .09]	0.261
Updating → AWP CON (c3)	0.033	0.027	1.212	0.225	[-.02, .09]	0.085

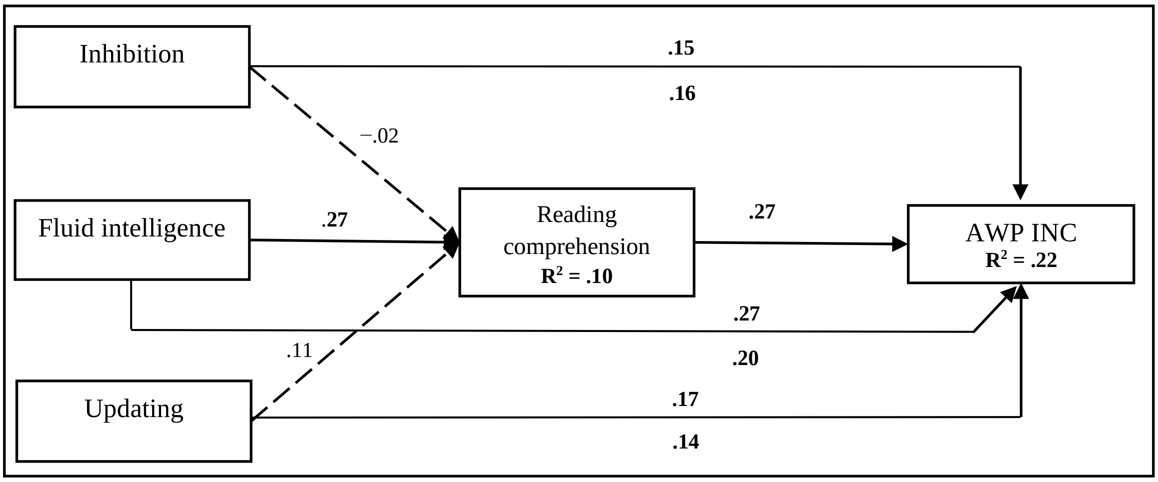
Note. AWP CON = performance on consistent arithmetic word problems.

Regarding inconsistent AWP-solving performance (AWP INC), results are presented in Figure 2.4 and Table 2.6. The total amount of variance explained by the model was R^2 = .22 (f^2 = .28). The effect of the mediator, reading comprehension, on AWP INC (Path *b*) was significant (*B* = .25; *SE* = .07; *β* = .27; *p* < .001; 95% CI [0.12, 0.38]). The total effects of executive functions on AWP INC (Paths *c*) were significant for inhibition (*B* = .02; *SE* = .01; *β* = .15; *p* < .035; 95% CI [0.00, 0.03]), fluid intelligence (*B* = .14; *SE* = .04; *β* = .27; *p* < .001; 95% CI [0.07, 0.21]), and updating (*B* = .18; *SE* = .07; *β* = .17; *p* = .012; 95% CI [0.04, 0.31]). When direct effects on AWP INC (Paths *c'*) were considered, significant relationships were found for inhibition (*B* = .02; *SE* =

.01; *β* = .16; *p* = .026; 95% CI [0.00, 0.03]), fluid intelligence (*B* = .11; *SE* = .04; *β* = .20; *p* = .004; 95% CI [0.03, 0.27]) and updating (*B* = .15; *SE* = .07; *β* = .14; *p* = .037; 95% CI [0.01, 0.27]). As for indirect effects of predictors AWP INC through the mediator variable (reading comprehension), only intelligence was significant (*B* = .04; *SE* = .02; *β* = .07; *p* = .019; 95% CI [0.02, 0.08]) after bootstrapping.

Figure 2.4

Path Model for Inconsistent AWP-Solving Performance



Note. Lines in bold indicate statistically significant relationships, whereas dashed lines indicate statistically non-significant relationships. AWP INC = performance on inconsistent arithmetic word problems.

Table 2.6

Direct, Indirect and Total Effects of Inhibition, Fluid Intelligence, Updating, and Reading Comprehension on Inconsistent AWP-Solving Performance

Inconsistent AWP	**Estimate**	**Std. error**	**z-value**	**P(>|z|)**	**95% CI**	**Std.all**
Reading comprehension (b1)	0.250	0.068	3.692	0.000	[.12, .38]	0.272
Inhibition (c'1)	0.016	0.007	2.228	0.026	[.00, .03]	0.158
Fluid intelligence (c'2)	0.105	0.036	2.896	0.004	[.03, .17]	0.198
Updating (c'3)	0.145	0.069	2.081	0.037	[.01, .27]	0.139
Reading comprehension						
Inhibition (a1)	-0.002	0.008	-0.251	0.802	[-.02, .01]	-0.018
Fluid intelligence (a2)	0.155	0.048	3.219	0.001	[.07, .25]	0.271
Updating (a3)	0.121	0.075	1.621	0.105	[-.03, .27]	0.107
Indirect effects						
Inhibition → Reading → AWP INC (a1xb1)	-0.001	0.002	-0.239	0.811	[-.01, .00]	-0.005
Intellig. → Reading → AWP INC (a2xb1)	0.039	0.017	2.346	0.019	[.02, .08]	0.074
Updating → Reading → AWP INC (a3xb1)	0.030	0.021	1.470	0.141	[.00, .08]	0.029
Total effects						
Inhibition → AWP INC (a1xb1+c1)	0.016	0.007	2.113	0.035	[.00, .03]	0.153
Intelligence → AWP INC (a2xb1+c2)	0.144	0.037	3.892	0.000	[.07, .21]	0.272
Updating → AWP INC (a3xb1+c3)	0.175	0.070	2.514	0.012	[.04, .31]	0.168

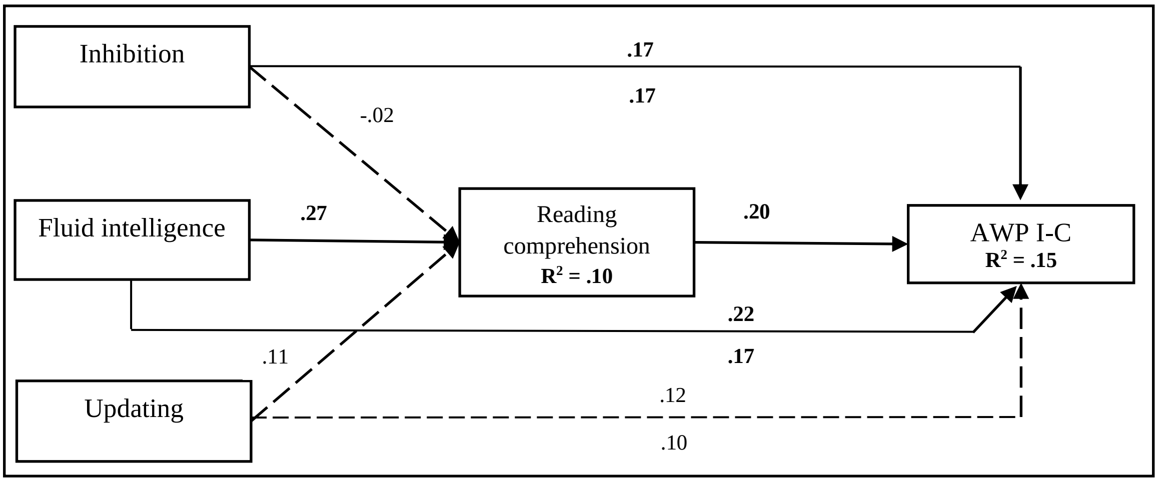
Note. AWP INC = performance on inconsistent arithmetic word problems.

Regarding the mixed inconsistent-then-consistent AWP (AWP I-C), results are presented in Figure 2.5 and in Table 2.7. The total amount of variance explained by the whole model was R^2 = .15 (f^2 = .18). The effect of the mediator, reading comprehension, on AWP I-C (Path *b*) was significant (*B* = .06; *SE* = .02; *β* = .20; *p* = .005; 95% CI [0.02, 0.10]). The total effects of executive functions on AWP I-C (Paths *c*) were significant for inhibition (*B* < .01; *SE* < .01; *β* = .17; *p* = .017; 95% CI [0.00, 0.01]) and fluid intelligence (*B* = .04; *SE* = .01; *β* = .22; *p* = .002; 95% CI [0.01, 0.06]), but not for updating (*B* = .04; *SE* = .03; *β* = .12, *p* = .100). When direct effects on AWP I-C (Paths *c'*) were considered, significant relations were found for inhibition (*B* = .01; *SE* < .01; *β* =

.17; *p* = .015; 95% CI [0.00, 0.01]) and fluid intelligence (*B* = .03; *SE* = .01; *β* = .17; *p* = .022; 95% CI [0.00, 0.06]), but not for updating (*B* = .04; *SE* = .03; *β* = .10; *p* = .173). As for indirect effects of predictors on AWP I-C through the mediator variable (reading comprehension), only intelligence was significant (*B* = .01; *SE* = .01; *β* = .05; *p* = .036; 95% CI [0.00, 0.02]) after bootstrapping.

Figure 2. 5

Path Model for Performance on Inconsistent-Then-Consistent AWPs



Note. Lines in bold indicate statistically significant relationships, whereas dashed lines indicate statistically non-significant relationships. AWP I-C = performance on consistent-then-inconsistent arithmetic word problems.

Table 2.7

Direct, Indirect and Total Effects of Inhibition, Fluid Intelligence, Updating, and Reading Comprehension on Inconsistent-Then-Consistent AWP-Solving Performance

AWP I-C	Estimate	Std. error	z-value	P(>|z|)	95% CI	Std.all
Reading comprehension (b1)	0.061	0.021	2.839	0.005	[.02, .10]	0.197
Inhibition (c'1)	0.006	0.002	2.442	0.015	[.00, .01]	0.173
Fluid intelligence (c'2)	0.030	0.013	2.291	0.022	[.00, .06]	0.169
Updating (c'3)	0.035	0.026	1.363	0.173	[-.02, .08]	0.100
Reading comprehension						
Inhibition (a1)	-0.002	0.008	-0.249	0.803	[-.02, .01]	-0.018
Fluid intelligence (a2)	0.155	0.047	3.306	0.001	[.06, .25]	0.271
Updating (a3)	0.121	0.074	1.630	0.103	[-.03, .26]	0.107
Indirect effects						
Inhibition → Reading → AWP I-C (a1xb1)	-0.000	0.001	-0.233	0.816	[.00, .00]	-0.004
Intellig. → Reading → AWP I-C (a2xb1)	0.009	0.005	2.100	0.036	[.00, .02]	0.053
Updating → Reading → AWP I-C (a3xb1)	0.007	0.005	1.383	0.167	[.00, .02]	0.021
Total effects						
Inhibition → AWP I-C (a1xb1+c1)	0.006	0.002	2.389	0.017	[.00, .01]	0.170
Intelligence → AWP I-C (a2xb1+c2)	0.040	0.013	3.066	0.002	[.01, .06]	0.223
Updating → AWP I-C (a3xb1+c3)	0.042	0.026	1.642	0.100	[-.01, .09]	0.121

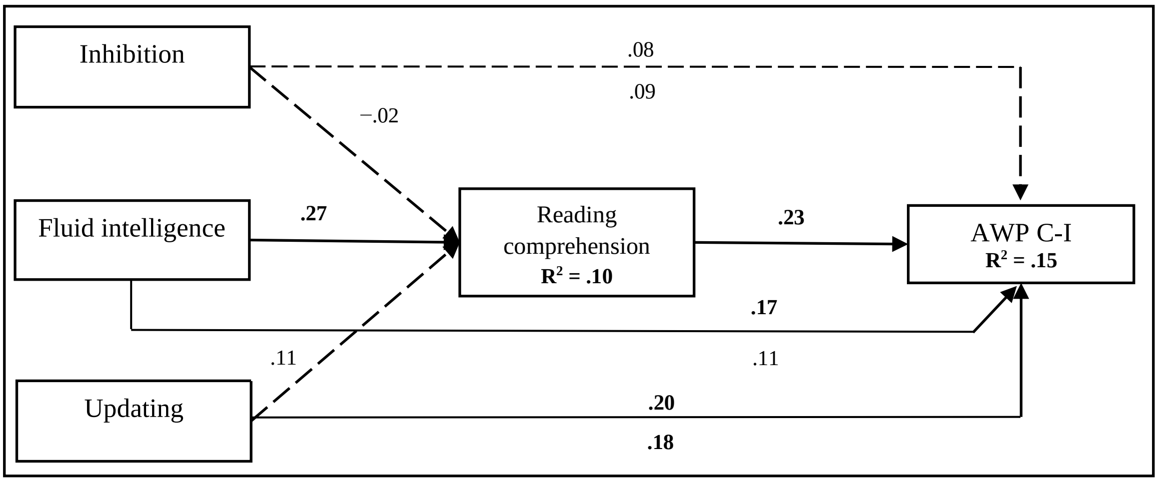
Note. AWP I-C = performance on inconsistent-then-consistent arithmetic word problems.

Finally, the results for consistent-then-inconsistent AWPs (AWP C-I) are presented in Figure 2.6 and Table 2. 8. The total amount of variance explained by the model was $R^2 = .15$ ($f^2 = .18$). The effect of the mediator, reading comprehension, on AWP C-I (Path *b*) was significant (*B* = .06; *SE* = .02; *β* = .23; *p* = .003; 95% CI [0.02, 0.11]). The total effects of domain-general cognitive abilities on AWP C-I (Paths *c*) were significant for fluid intelligence (*B* = .03; *SE* = .01; *β* = .17; *p* = .020; 95% CI [0.00, 0.05]) and updating (*B* = .06; *SE* = .02; *β* = .20; *p* = .005; 95% CI [0.02, 0.10]) but not for inhibition (*B* < .01; *SE* < .01; *β* = .08; *p* = .277). When direct effects on AWP-CI (Paths *c'*) were considered, significant relationships were found for updating (*B* = .05; *SE* = .02; *β* = .18; *p* =

.013; 95% CI [0.01, 0.09]), but not for inhibition (*B* < .01; *SE* < .01; *β* = .09; *p* = .235) or fluid intelligence (*B* = .02; *SE* = .01; *β* = .11; *p* = .141). As for indirect effects of predictors on AWP I-C through the mediator variable (reading comprehension), only intelligence was significant (*B* = .01; *SE* = .01; *β* = .06; *p* = .036; 95% CI [0.00, 0.02]) after bootstrapping.

Figure 2.6

Path Model for Performance on Consistent-Then-Inconsistent AWPs (AWP C-I)



Note. Lines in bold indicate statistically significant relationships, whereas dashed lines indicate statistically non-significant relationships. AWP C-I = performance on consistent-then-inconsistent arithmetic word problems.

Table 2. 8

Direct, Indirect and Total Effects of Inhibition, Fluid Intelligence, Updating, and Reading Comprehension on Consistent-Then-Inconsistent AWP-Solving Performance

AWP C-I	**Estimate**	**Std. error**	**z-value**	**P(>|z|)**	**95% CI**	**Std.all**
Reading comprehension (b1)	0.063	0.021	2.959	0.003	[.02, .11]	0.233
Inhibition (c'1)	0.003	0.002	1.189	0.235	[.00, .01]	0.085
Fluid intelligence (c'2)	0.017	0.011	1.474	0.141	[-.01, .04]	0.109
Updating (c'3)	0.054	0.022	2.484	0.013	[.01, .09]	0.177
Reading comprehension						
Inhibition (a1)	-0.002	0.008	-0.247	0.805	[-.02, .01]	-0.018
Fluid intelligence (a2)	0.155	0.048	3.271	0.001	[.06, .25]	0.271
Updating (a3)	0.121	0.076	1.599	0.110	[-.03, .26]	0.107
Indirect effects						
Inhibition → Reading → AWP C-I (a1xb1)	-0.000	0.001	-0.233	0.816	[.00, .00]	-0.004
Intellig. → Reading → AWP C-I (a2xb1)	0.010	0.005	2.101	0.036	[.00, .02]	0.063
Updating → Reading → AWP C-I (a3xb1)	0.008	0.005	1.403	0.161	[.00, .02]	0.025
Total effects						
Inhibition → AWP C-I	0.002	0.002	1.087	0.277	[.00, .01]	0.081
Intelligence → AWP C-I	0.027	0.012	2.322	0.020	[.00, .05]	0.172
Updating → AWP C-I	0.062	0.022	2.820	0.005	[.02, .10]	0.202

Note. AWP C-I = performance on consistent-then-consistent arithmetic word problems.

The effect sizes of the presented models are medium (except for total AWP) demonstrating that all models included relevant cognitive factors. In the case of the total AWP, the effect size is large (probably due to a large number of AWPs) and give additional support that all the cognitive variables considered in the present study are relevant in explaining the AWP-solving performance.

2.4 Discussion

The present study had the aim to shed new light on the role of some cognitive variables (i.e., inhibition, updating, fluid intelligence, and reading comprehension) in constructing a situational problem representation, considering consistent and inconsistent AWPs. First, as expected and in line with existing literature (Hegarty et al., 1995; Lewis & Mayer, 1987; Pape, 2003), the results confirmed a *consistency effect* (Hypothesis 1). Participants performed more accurately on consistent AWPs than inconsistent ones. This outcome is in agreement with findings that lexical consistency facilitates problem-solving (Daroczy et al., 2015) by allowing a direct translation strategy, whereas inconsistency requires a deeper level of processing. Indeed, it should be noted that the sample considered in the present study: (a) obtained a very high percentage of correct answers for consistent AWPs, although the number of operations was a factor contributing to the problems' difficulty (Castro-Martínez & Frías-Zorilla, 2013; Quintero, 1983); and (b) two-operation consistent AWPs were easier than either AWP I-C or AWP C-I, where children are required to solve one consistent and one inconsistent operation.

Second, the results showed the effect of number of operations on AWP-solving accuracy, with two-step problems being more challenging than one-step problems (Vessonen et al., 2024). However, the effect of lexical inconsistency was even more pronounced (Hypothesis 2). This suggests that the difficulty in solving AWPs is not solely due to the number of operations required but is also strongly influenced by the cognitive requirements imposed by the problem's representation (see Fuson, 1992; Hasanah et al. 2017; Thevenot, & Barrouillet, 2015). Indeed, semantic elements of AWPs influence their difficulty (e.g., Boonen et al., 2016; Daroczy et al., 2015; De Corte et al., 1985; Pape, 2003). As mentioned in the Introduction, a key aspect differentiating inconsistent AWPs from consistent AWPs concerns the lexical inconsistency, namely the conflict between the relational term and the arithmetical operation required to solve an inconsistent problem. In inconsistent AWPs, it is not possible to use a superficial strategy, namely the direct translation strategy (Schumacher & Fuchs, 2012). Instead, the child must use a problem-model strategy. This involves translating the proposition-based representation into a situational model or object-based representation representing the appropriate relationships between the numerical variables (de Koning et al., 2017; Hegarty et al., 1995; Thevenot, 2010) and then planning and executing the required arithmetic operations.

Such nonroutine thinking to solve inconsistent AWPs requires reflection and a controlled application of executive processes, such as inhibition and updating of the problem's information in the WM (Hypothesis 3). This is supported by our finding that demonstrated a different pattern of contributions of updating and inhibition to AWP-solving depending on the problem type. When we consider the overall performance (AWP TOT), the results confirmed that both executive functions—inhibition and updating—were distinct and significant predictors of AWP-solving accuracy. Moreover, we found that fluid intelligence had both direct and indirect effects (mediated by reading comprehension) on the overall measure of AWP-solving performance. In other words, fluid intelligence contributed a unique part of the variance in AWP-solving accuracy, even after accounting for reading comprehension ability. This model explained a moderate proportion of variance (30%) in total AWP-solving accuracy. The magnitude of the β weights revealed that reading comprehension is the most important predictor of AWP-solving ability in fourth and fifth grades of primary school, followed by fluid intelligence, with inhibition and updating playing smaller but still important roles.

Interestingly, the role of inhibition and updating changed when considering different problem types. Regarding inhibition, results demonstrated its contribution to explaining accuracy on consistent, inconsistent, and I-C AWPs. As suggested by Passolunghi and Siegel (2001), inhibition is a core ability necessary to select and disregard irrelevant and unneeded information and therefore would be required in the solving process of various problem types. However, our results also showed that inhibition lost relevance in C-I problems in favor of updating abilities. Updating is a more complex cognitive process, as it entails comparison processes, the inhibition of no longer relevant information and its substitution with new one, and resistance to interference (see for example Linares, et al., 2016). It must be noted that C-I problems were the most difficult problem type in our sample and thus it could be speculated that problem's difficulty may increase the demand on the solver's ability to update and integrate information (Agostino et al., 2010) in order to create a coherent mental representation of the problem. In line with this idea, we found updating abilities to explain accuracy on more difficult problem types (i.e., C-I and inconsistent problems) but not on the easier ones (i.e., I-C and consistent problems). This pattern suggests that updating is an important skill involved in those problems that require a complex problem representation.

Moreover, it is highly interesting that after controlling for participants' updating abilities, the differences in accuracy between AWP C-I and I-C disappeared. This result gives additional support to the assumption that updating ability is strongly related to the ability to build a correct mental representation of a problem and then solve it (Iglesias-Sarmiento et al., 2015; Passolunghi & Pazzaglia, 2005; Thevenot & Barrouilllet, 2015). Failure to inhibit the strong association between the keyword in the text statement (e.g., *more*) and the operation (e.g., addition) and to update the representation, switching from the propositional one to the situational one, would tend to prompt a superficial, erroneous response.

To sum up, this study contributes valuable new insights into the relationships between fluid intelligence, reading comprehension, executive functions, and AWP-solving performance, particularly in the context of consistent and inconsistent problems. We demonstrated that AWP-solving relies on reading comprehension and, importantly, on reasoning and the central executive processes involved in actively processing information, updating relevant information, and inhibiting irrelevant information and inappropriate strategies. These domain-general factors are important, each in their own right, in explaining children's performance in consistent and inconsistent AWPs. Finally, these results highlight the importance of considering problem type and problem complexity when investigating the role of cognitive factors in AWP-solving.

The results of the present study should be interpreted in light of some limitations. A first possible limitation arises from the fact that a shifting measure is lacking. Some authors (e.g., Toll et al., 2010) have suggested, however, that the role of shifting in mathematics would relate to the complexity of the task at hand and the required knowledge. This being the case, shifting might be minimal in such AWPs as those analyzed in the present study. Another limitation concerns factors not examined here, which could influence and explain variability in AWP-solving performance (e.g., Fung & Swanson, 2017). For instance, individual differences and domain-general factors such as processing speed, attention, and visuospatial abilities may contribute to performance in AWP-solving (see Boonen et al., 2013; Cragg et al., 2017; Passolunghi & Lanfranchi, 2012). The relationships observed in this study might change with the inclusion of additional variables, and future research should seek to refine and expand the proposed model.

Nevertheless, these findings underscore the importance of teaching students to integrate a problem's textual information into a coherent mental representation, which is the basis for choosing an effective solution strategy (Jimenez & Verschaffel, 2014; Thevenot & Oakhill, 2005; Verschaffel et al., 2020). Indeed, solving an AWP is not simply a matter of arithmetic operations; it also requires comprehending the text, integrating relevant information in an accurate mental model of the problem, and applying appropriate solution strategies. Educational interventions that focus on comprehension skills, controlled thinking, and working memory processes could be an effective approach to enhancing AWP-solving abilities (e.g., Boonen et al., 2016; Cornoldi et al., 2015; Fuchs et al., 2020). Understanding the role of these cognitive factors is essential for developing tailored training programs that enhance students' AWP-solving abilities.

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3. STUDY TWO

Arithmetic Word Problem-Solving and Math Anxiety: The Role of Perceived Difficulty and Gender[2]

Abstract

A crucial component of mathematics curricula in primary education is the ability to solve arithmetic word problems (AWPs). Previous studies investigated predominantly the cognitive factors underlying this skill, neglecting the role of emotional (e.g., math anxiety – MA) and metacognitive (e.g., perceived task difficulty) aspects. Some findings have suggested that emotional factors could influence perceived task difficulty which would, in turn, impair student performance. However, the relationship between MA, perceived task difficulty and AWP-solving performance has not yet been explored. Moreover, although many studies have reported gender differences in MA levels, findings regarding primary school children are mixed. This study aimed to evaluate the role of MA and perceived task difficulty on AWP-solving proficiency in a sample of Italian primary school students, and to investigate gender differences in these variables. Results showed that MA had a direct and indirect effect through perceived difficulty on AWP-solving performance. Findings confirmed that girls exhibited higher MA levels, however no significant gender differences were observed in AWP-solving accuracy or perceived task difficulty. These findings emphasize the need to consider emotional factors when investigating children's difficulties in AWP-solving and underscore the importance of MA interventions in primary education, especially for girls.

3.1 Introduction

Arithmetic word problems (AWPs) are a crucial component of math school curricula across all educational levels, beginning in primary school (Daroczy et al., 2015). AWP-solving represents a

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[2] Adapted from Doz, E., Cuder, A., Pellizzoni, S., Carretti, B., & Passolunghi, M. C. (2023). Arithmetic Word Problem-Solving and Math Anxiety: The Role of Perceived Difficulty and Gender. *Journal of Cognition and Development, 24*(4), 598–616. https://doi.org/10.1080/15248372.2023.2186692

fundamental learning activity since it prepares students to apply mathematical notions to real-world situations (Pongsakdi et al., 2020; Swanson & Fung, 2016). However, many students, from primary school through adulthood, struggle with this type of math task (Daroczy et al., 2015; Hegarty et al., 1992; Lewis & Mayer, 1987; Verschaffel et al. 1992). Therefore, it is essential to investigate the underlying factors that may facilitate or hinder students' ability to solve AWPs.

Previous studies on AWP-solving in primary school children have primarily focused on the cognitive abilities involved in the solving process (Fuchs et al., 2018; Fung & Swanson, 2017; Mori & Okamoto, 2016; Passolunghi et al., 2022; Peng et al., 2016; Wang et al., 2016), while largely neglecting the influence of emotional-motivational aspects (Hoffmann, 2010). Among these factors, math anxiety (MA) has been widely recognized to negatively impact students' general math achievement (see Namkung et al., 2019). Nevertheless, far less is known about the specific relationship between MA and AWP-solving proficiency, with relatively few studies (e.g., Lai et al., 2015; Passolunghi et al., 2019; Ramirez et al., 2013, 2016) investigating this association in primary school children. Notably, emotions are believed to influence metacognitive experiences of task difficulty (Efklides, 2011): research suggests that students in a positive emotional state are likely to feel optimistic and perceive the task as less difficult, while negative mood can heighten perceived difficulty (Efklides & Petkaki, 2005), ultimately leading to poorer performance (Nuutila et al., 2021). Despite this, to the best of our knowledge, no study has examined the relationship between MA, perceived task difficulty, and AWP-solving abilities. Gender differences also add complexity to the relationship between MA and math performance. While some studies indicate that females are more prone to MA (e.g., Xie et al., 2019), it is unclear whether this gender disparity is present as early as primary school (e.g., Dowker et al., 2012; Hill et al., 2016).

The overall aim of the present study was to deepen our understanding of the role of MA in AWP-solving by exploring the relationships between MA, perceived task difficulty, and AWP-solving proficiency in a sample of primary school children, and by examining gender differences in these constructs. This investigation can provide novel theoretical insight into the factors contributing to difficulties in AWP-solving and clarify the mechanisms through which MA affects performance. Additionally, it may offer practical guidance for supporting children who struggle with AWP-solving.

3.1.1 Arithmetic Word Problem-Solving

An AWP is defined as a specific type of arithmetic problem which is presented in a short narrative notation (Verschaffel et al., 2000). From a cognitive point of view, solving AWPs is a complex activity (Duque de Blas et al., 2021), as the complete process involves several phases (Mayer & Hegarty, 1996) and various cognitive abilities (e.g., fluid intelligence, reading comprehension, working memory, executive functions; Lin, 2021; Passolunghi et al., 2022). For successful AWP-solving, individuals need to understand the text of the problem, translate each sentence into an internal representation of the problem situation, integrate and detect relevant information, plan the mathematical procedure they are willing to apply, and finally execute the necessary arithmetic computations (Lewis & Mayer, 1987).

Several different types of AWPs exist. Riley et al. (1983) identified three types of simple AWPs that are frequently offered in primary education: combine, change, and compare problems. In the present study, we focused on compare problems, as students exhibit significantly more difficulty with these problems than with other types, even though the corresponding math is similar (Boonen & Jolles, 2015; Giroux & Ste-Marie, 2001; Riley & Greeno, 1988; Schumacher & Fuchs, 2012; Stern, 1993). This makes the investigation of compare-type word problems particularly important. Compare problems contain a relational term (e.g., more than, less than) that compares the numerical values of two variables. Based on the semantic of the relational term, we can distinguish two subtypes of compare problems (Hegarty et al., 1992): consistent and inconsistent problems. In consistent problems (e.g., “Susan has 8 pencils. Michael has 5 pencils more than Susan. How many pencils has Michael?”), the relational term (e.g., more than) is semantically coherent or consistent with the arithmetic operation required to find the solution (e.g., addition). In inconsistent problems (e.g., “Susan has 8 pencils. She has 5 pencils more than Michael. How many pencils has Michael?”), the relational term is semantically incoherent with the arithmetic operation (i.e., subtraction).

3.1.2 Math Anxiety

Mathematics and AWP-solving depend not only on cognitive abilities but also on emotional-motivational factors. Among these, MA has been recognized to play a significant role (Dowker et al., 2012). MA is a specific emotional response defined as a feeling of tension and anxiety that interferes with the execution of tasks involving numbers, not only in the academic context, but also in everyday life situations (Richardson & Suinn, 1972). In literature, MA is both conceptualized as a trait or state construct (Cipora et al., 2022) reflecting different understandings of MA. It has been largely proven that trait MA has a detrimental effect on mathematical achievement: high levels of MA are linked to lower math performance (for a review see, Barroso et al., 2021).

Although the modulating role of MA on math abilities has been extensively studied, mathematics is a heterogeneous school subject and each area of mathematics requires different combinations of skills (Dehaene, 1992; LeFevre et al., 2010) and could be differently affected by the same emotional response (Zhang et al., 2019). Previous research has mostly focused on investigating the effects of MA on general math achievement or on various arithmetic and computation tasks (e.g., Harari et al., 2013; Hill et al., 2016; Lee & Cho, 2018; Passolunghi et al., 2016), while much less attention has been paid to AWP-solving (e.g., Kyttälä & Björn, 2014; Passolunghi et al., 2019). Recent studies have furtherly suggested that the relation between MA and math performance differs based on the aspect of mathematics under evaluation (Caviola et al., 2022). In particular, MA seems to strongly impair the accuracy of mathematical reasoning tasks that involve complex cognitive skills (Wu et al., 2012), whereas the association is less pronounced when assessing basic computational skills (Harari et al., 2013; Wu et al., 2012). Therefore, our study aimed to extend previous research by evaluating the specific relationship between MA and AWP-solving ability.

It is important to note that the role of MA in math achievement has typically been investigated in adults and older children, while the relationship between MA and math performance in primary school students remains inconclusive (Zhang et al., 2019). Some authors have failed to find an association between MA and math proficiency in primary school students (Dowker et al., 2012; Haase et al., 2012; Krinzinger et al., 2009; Thomas & Dowker, 2000; Wood et al., 2012), whereas others have reported that the MA-performance link exists even at this early age (Cargnelutti et al., 2017; Jameson, 2013; Vukovic et al., 2013; Wu et al., 2012, 2014; Živković et al., 2022). Investigating MA in young children is crucial for understanding the sources of difficulties they may encounter in math learning and, if possible, preventing the early development of negative emotions toward math-related activities. Hence, in the present study we decided to focus on a sample of primary school children.

3.1.3 Perceived Task Difficulty

An important factor related to student performance is the construct of perceived task difficulty (Nuutila et al., 2021). This is a metacognitive experience (Efklides, 2011) defined as a subjective judgment of task difficulty that can be evoked before, during and after the completion of a task (Efkildes et al., 1998). According to the theoretical model of metacognition, motivation and affect (MASRL model; Efklides, 2011, 2019), the feeling of task difficulty is metacognitive in nature since it derives from the monitoring of the ongoing cognitive processing of the task and its awareness provides input for self-regulation, strategy use, effort, and affect (Efklides & Petkaki, 2005). In this study we focused on retrospective evaluations of task difficulty (i.e., after completing the task) since they are believed to capture feelings of difficulty linked to the overall solving process (Brown, 1978; Efklides, & Petkaki, 2005).

It is noteworthy that perceived difficulty is distinct from the objective difficulty of the task. Indeed, research has found that the evaluation of difficulty is partly based on assessments of objective difficulty, such as task characteristics, complexity, and novelty (Efklides et al., 1998; Vangsness & Young, 2018), but it is also affected by subjective factors including emotional aspects (Efklides, 2002; Fulmer & Tulis, 2013). For instance, Efklides and Petkaki (2005) experimentally induced in a sample of late primary school children a positive or negative mood and found that students in a positive mood state were more likely to report that a word problem-solving task was easier than students who were induced with a negative affect. Judging a task as moderately demanding may increase performance (Atkinson, 1957; Brunstein & Schmitt, 2010), whereas high levels of perceived task difficulty are likely to impair one's achievement (Nuutila et al., 2021).

Taken together, emotional states (e.g., mood) seem to influence perceived task difficulty, which, in turn, impacts student performance (Hascher, 2010). However, the understanding on how trait emotions (i.e., stable personal characteristics) and perceived difficulty are related to math outcomes is still very scarce and to the best of our knowledge no study has investigated the relationship between math-related emotions such as MA, perceived task difficulty, and AWPs.

3.1.4 Gender Differences

A gender difference related to MA has been extensively documented. Previous research involving adults and high school students has consistently found that females tend to have higher levels of MA (e.g., Else-Quest et al., 2010; Jansen et al., 2016; Ferguson et al., 2015; Xie et al., 2019). However, gender differences regarding MA in primary school students have been far less investigated (Hill et al., 2016). Some studies have revealed that primary school girls experience significantly higher MA than boys (e.g., Carey et al., 2017; Hill et al., 2016; Szczygieł, 2019; Vanbinst et al., 2020), while other studies did not replicate the same results (e.g., Dowker et al., 2012; Gierl & Bisanz, 1995; Harari et al., 2013; Punaro & Reeve, 2012; Ramirez et al., 2013; Young et al., 2012).

Concerning math achievement, older meta-analyses have indicated a male advantage in mathematics (Hedges & Nowell, 1995; Hyde et al., 1990). However, this gender gap seems to be disappearing, with more recent studies suggesting small or insignificant gender differences in math attainment (Devine et al., 2012; Dowker et al., 2012; Hill et al., 2016; Hyde et al., 2008; Lindberg et al., 2010; Rossi et al., 2022; Vanbinst et al., 2020).

As regards to perceived task difficulty, a very limited number of studies have sought to explore gender related differences in this construct. Graf and Riddell's (1972) study investigated whether the retrospective evaluations of word problem difficulty differed among male and female university students, finding no significant differences in the perception of word problems with neutral context. Nuutila et al. (2021) found in a sample of middle schoolers that girls reported higher perceived difficulty in the beginning of a problem-solving task (i.e., expected perceived difficulty). However, no gender differences were observed in the evaluations of difficulty during and after the completion of the task.

3.1.5 The Present Study

Considering the limited and contradicting findings on the issue, the overall purpose of the present study was to advance the understanding of the role of MA and perceived task difficulty in solving AWPs, and more specifically, compare problems, and evaluate gender differences in these variables in primary school children. In doing this, we aimed to extend previous studies in several ways.

Firstly, our aim was to explore the contributions provided by MA and perceived task difficulty in explaining the variance of children's AWP-solving performance. We hypothesized, in accordance with studies conducted on other AWP types (e.g., Passolunghi et al., 2019; Ramirez et al., 2013, 2016) and in accordance with studies that suggest a stronger relationship between MA and complex math tasks (e.g., Wu et al., 2012), that MA would negatively predict proficiency on compare problems. In addition, we hypothesized that also perceived task difficulty would negatively predict children's AWP-solving accuracy (Nuutila et al., 2021).

Secondly, we wanted to inspect the possible mediational role of perceived task difficulty in the relationship between MA and AWP-solving achievement. Based on previous results on mood states (Efklides & Petkaki, 2005), we expected that high MA levels would lead to higher perceptions of difficulty, which would consequently negatively impact AWP-solving performance. We judged this analysis fundamental to provide understanding on the role and mechanisms of MA in AWP-solving.

Lastly, we were interested in evaluating whether there are gender differences in MA, perceived problems' difficulty, and AWP-solving performance in primary school children. Based on existing studies, we expected that girls would experience higher MA (Carey et al., 2017; Hill et al., 2016; Szczygieł, 2019; Vanbinst et al., 2020), but we hypothesized no gender differences in mathematics performance (Devine et al., 2012; Dowker et al., 2012) nor in perceived problems' difficulty (Graf & Riddell, 1972; Nuutila et al., 2021).

3.2 Method

3.2.1 Participants and Procedure

Participants were 111 students attending Grade 5 of five different primary schools located in the northeast part of Italy. Four children were excluded from the analysis due to missing data. Thus, the sample analyzed included 107 students (59 F) with a mean age of 10 years and 3 months. The socio-economic status of the sample was primarily middle class, established on the basis of school records. For sample size estimation, an a priori power analysis was conducted. Results indicated that the minimum sample size needed to achieve power = .80 for detecting a medium effect, at a significance criterion of $\alpha = .05$, was N = 80 for mediation. Thus, our sample size of N = 107 is adequate.

After obtaining parental consent, children were tested in two sessions administered at school. In the first session, MA was evaluated. The second session included the assessment of AWP-solving and perceived task difficulty. The study obtained approval by the ethical committee of the University of Trieste and was carried out in compliance with the Declaration of Helsinki and the ethical guidelines of the Italian Association of Psychology.

3.2.2 Measures

Arithmetic Word Problem Task

To measure students' AWP-solving skills, we administrated an untimed task adapted from Hegarty and colleagues (1992). Contrary to previous works that measured AWP-solving ability using a mixed variety of math problems (e.g., Ramirez et al., 2013; Wu et al., 2012), the present study focused solely on compare problems. We employed this type of AWPs since it is frequently offered in primary education (Powell et al., 2020; Riley et al., 1983) and is particularly difficult to solve although the corresponding math and language is relatively simple (Boonen & Jolles, 2015; Daroczy et al., 2015; Giroux & Ste-Marie, 2001; Riley & Greeno, 1988; Schumacher & Fuchs, 2012). Indeed, the complexity derives from the lexical inconsistency and the need to construct a mental representation of the problem situation (de Koning et al., 2022; Passolunghi et al., 2022), which is the "heart of word problem solution" (Ng & Lee, 2009, p. 284). Specifically, the task contained 8 compare word problems, which required two elementary arithmetic calculations consisting of addition and subtraction to be solved. The problems are similar to those assigned by teachers to students at the considered school grade. Each problem included four short sentences. The first sentence was an assignment statement expressing the price of a variable (e.g., "A pair of skates at Outdoor costs 40 euros"). The second sentence was a relational statement denoting the value of a second variable in relation to the first one (e.g., "A pair of skates at Happy-bike costs 10 euros more than a pair of skates at Outdoor"). The third sentence was another relational statement indicating the value of a third variable in relation to the second one (e.g., "The pair of skates at Happy-bike costs 5 euros more than an electric skateboard"). The last part was a question asking about the value of the third variable (e.g., "How much does an electric skateboard cost?"). Thus, each problem contained two relational statements, one consistent and the other inconsistent. The order of the consistent and inconsistent statement was manipulated. Moreover, half of the problems contained the relational term “more than” and the other half contained the relational term “less than”. The score of 0 or 1 was attributed to each problem according to whether the answer was incorrect or correct, respectively. Its score range was between 0 and 8. Cronbach’s α for internal consistency was .86.

Perceived Difficulty of the Problems

After completing each problem, students were asked to evaluate its perceived difficulty on a Likert scale ranging from 1 to 7 (1 = very easy, 7 = very difficult). A 7-point Likert scale was used in accordance with previous studies (Nuutila et al., 2021). The total score of perceived difficulty could range from 8 to 56. The internal consistency reliability was good ($r = .83$).

Math Anxiety

The adaptation of the *Abbreviated Math Anxiety Scale* for primary school (AMAS; Hopko et al., 2003; Italian version adapted for primary school students by Caviola et al., 2017) was administered to evaluate children’s trait MA. AMAS is a brief self-report tool that comprises nine items depicting situations involving mathematical activities and number manipulations (e.g., “Listening to a lecture in math class”). Participants had to judge every statement in terms of how anxious they would feel in each described situation, using a five-point Likert scale (1 = a little anxious; 5 = extremely anxious). The total score of each participant could range from 9 to 45. The internal consistency of the scale was good (Cronbach’s α = .81). AMAS was selected since (1) it is one of the most widely used instrument to assess MA (Primi et al., 2020) allowing us to compare our results to findings from numerous other studies; (2) it shows psychometric properties comparable to those of the longer MA scale (MARS-R; Plake & Parker, 1982), as well as high convergent validity (Hopko et al., 2003); (3) its briefness makes it a convenient and appropriate measure for primary school children (Martín-Puga et al., 2022). Moreover, it must be noted that some MA measures used by previous studies (e.g., Ramirez et al., 2013; Wu et al., 2012) are excessively age-restricted or adequate statistics supporting their validity are not provided (see Carey et al., 2017).

3.3 Results

Statistical analyses were performed with SPSS software (version 21). Table 3.1 reports descriptive statistics of all variables, including the mean, standard deviation, and zero-order correlations. From the inspection of the correlation results, it is possible to notice that MA was negatively correlated with AWP-solving scores ($r = -.43$, $p < .001$). Perceived difficulty was positively correlated with MA ($r = .52$, $p < .001$) and negatively with AWP-solving performance ($r = -.40$, $p = .001$).

Table 3.1

Descriptive Statistics and Bivariate Correlations Between All Variables

Variable	*M*	*SD*	1.	2.	3.
1. Math anxiety	21.24	5.66	—	−.43**	.52**
2. AWP-solving	3.62	2.63		—	−.40**
3. Perceived difficulty	20.65	10.84			—

Note. AWP = arithmetic word problem.

** $p < 0.01$

3.3.1 Multiple Regression Analysis

To verify the role of MA and perceived task difficulty in predicting the AWP-solving accuracy, we conducted a multiple regression analysis. Specifically, MA and perceived task difficulty were introduced as the independent variables while the AWP-solving performance as the dependent variable.

The overall regression was statistically significant ($R^2 = .213$), $F(2, 104) = 15.353$, $p < .001$. The model indicated that roughly one fifth of the variance in AWP-solving performance was accounted for by the linear combination of MA and perceived task difficulty. The regression model showed that both MA (β = –.306, t = –3.037, p = .003) and perceived task difficulty (β = –.240, t = –2.383, p = .019) significantly and negatively predicted AWP-solving performance.

3.3.2 Mediation Analysis

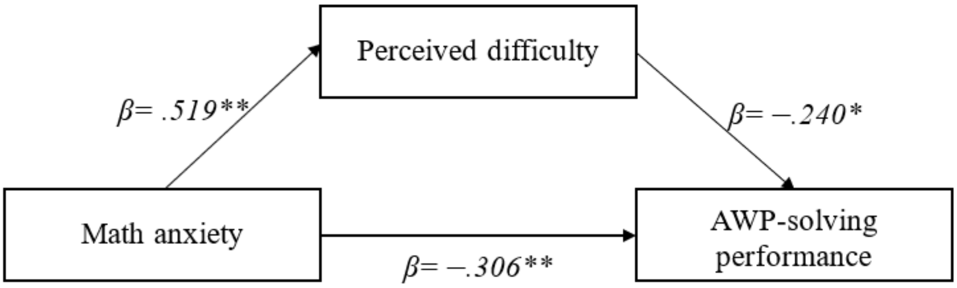
We hypothesized that higher MA would lead to a higher evaluation of problem difficulty, which would then decrease the respondents' ability to solve those problems. To test this assumption, Model 4 of the SPSS add-on PROCESS was utilized (Hayes, 2017). 5000 bootstrap samples were used to generate 95% bias-corrected and accelerated confidence intervals; if the 95% confidence interval of the indirect effect excludes zero, significance of the effect can be assumed (Hayes, 2017).

A mediation model was calculated placing MA as the focal regressor, AWP-solving accuracy as the dependent variable and perceived task difficulty as the mediator. The results are presented in Figure 3.1. Findings revealed that MA was significantly and negatively related to AWP-solving performance (β = –.306, s.e. = .047, p = .003). MA was significantly and positively associated to perceived task difficulty (β = .519, s.e.= .159, p < .001) and perceived task difficulty was negatively associated to AWP-solving performance (β = –.240, s.e. = .024, p = .019). Using 5000 bootstrapped samples, a significant indirect effect (IE= –.058, bootstrap s.e.= .026, 95% CI: [–0.109, –0.005]), and direct effect (DE= –.142, s.e.=.047, 95% CI: [–0.235, –.049]) were observed.

Thus, it can be concluded that MA had both a direct effect and indirect effect through perceived problem difficulty on AWP-solving performance. It must be pointed out that when positioning perceived difficulty as the focal regressor, MA as the mediator and AWP-solving achievement as dependent variable, the indirect effect was significant. Nevertheless, we selected the model with perceived difficulty as the mediator since it is a theory-driven model: one could expect that a trait characteristic influences on-task metacognition, whereas the inverse directionality could be possible when considering state characteristics instead of trait ones (Hong, 1999).

Figure 3.1

Results of the Mediation Analysis



Note. Math anxiety was inserted as the focal regressor, perceived difficulty as the mediator and AWP-solving performance as the outcome variable. Standardized regression coefficients are presented. AWP = arithmetic word problem.

*$p < 0.05$, ** $p < 0.01$.

3.3.3 Gender differences

A Multivariate Analysis of Variance (MANOVA) was conducted to evaluate whether females and males differed in regard to MA, perceived task difficulty, and AWP-solving performance. Gender was placed as fixed factor, whereas scores of MA, perceived task difficulty, and AWP-solving as dependent variables. Cohen's criteria (1988) were used to classify the effect size: small ($\eta_p^2 = 0.01$), medium ($\eta_p^2 = 0.06$), and large effect ($\eta_p^2 = 0.14$).

A statistically significant MANOVA effect was obtained, Wilk's Lambda = .907, $F(3, 103) = 3.520$, $p = .018$. Follow up comparisons indicated that girls ($M = 22.56$, $SD = 5.25$) compared to boys ($M = 19.63$, $SD = 5.77$) reported a significantly higher level of MA, $F(1, 105) = 7.558$, $p = .007$, $\eta_p^2 = .067$. There was no significant effect of gender on AWP-solving accuracy: girls ($M = 3.69$, $SD = 2.49$) and boys ($M = 3.52$, $SD = 2.81$) did not differ on AWP-solving performance, $F(1, 105) = 0.115$, $p = .735$, $\eta_p^2 = .001$. Moreover, female ($M = 21.73$, $SD = 11.02$) and male students ($M = 19.33$, $SD = 10.58$) did not differ on perceived difficulty of problems, $F(1, 105) = 1.296$, $p = .257$, $\eta_p^2 = .012$.

3.4 Discussion

To date, most developmental studies on AWP-solving have focused on cognitive skills associated with this ability, whereas research examining the influence of emotional-motivational aspects has remained relatively sparse. Given the prominent role of AWPs in mathematical education and everyday life (Fuchs et al., 2006), the main objective of the present research was to provide novel insight into the relationship between emotional factors (e.g., MA), metacognitive experiences (e.g., perceived task difficulty) and AWP-solving proficiency in a sample of primary school students. Specifically, we explored the contribution of both MA and perceived task difficulty on AWP-solving accuracy and investigated whether perceived task difficulty could mediate the relationship between MA and AWP-solving proficiency. Moreover, we sought to clarify whether gender differences in those variables may occur in children attending primary school.

Results confirmed our expectations revealing a negative direct effect of MA on children's performance on AWPs. This finding is consistent with those of previous studies involving primary school students, which reported that MA is negatively related to general math achievement (Cargnelutti et al., 2017; Sorvo et al., 2017; Vukovic et al., 2013; Wu et al., 2012, 2014) and, specifically, to AWP-solving accuracy (Lai et al., 2015; Passolunghi et al., 2019; Ramirez et al., 2013, 2016). However, not all studies found a detrimental effect of MA on math performance among young children (Dowker et al., 2012; Haase et al., 2012; Krinzinger et al., 2009; Thomas & Dowker, 2000; Wood et al., 2012). As reported by Zhang et al. (2019), one possible reason explaining these conflicting results is that the relationship between MA and math achievement depends on the measures used to assess math outcomes. In particular, the MA-performance link is stronger when students engage with demanding math tasks which require more cognitive engagement (Caviola et al., 2022). For instance, Wu et al. (2012) found a stronger correlation between children's MA and scores on a complex mathematical reasoning task (e.g., math problems with both verbal and visual prompts). In contrast, the correlation was weaker between MA and a simple calculation math task that required well learned and automatized skills. Since solving AWPs is a complex process (Pongsakdi et al., 2020), it might be particularly hindered by MA, whereas more basic math abilities might be less affected (Beilock & Carr, 2001). Our study has provided evidence on the link between MA and AWP-solving even in an untimed math task, highlighting the pervasive role of MA and the need to consider this negative emotion when investigating children's difficulties in this math domain.

Moreover, the current work has showed MA to have an indirect effect on AWP-solving performance through the metacognitive experience of perceived task difficulty. More specifically, high levels of MA were related to a higher evaluation of the problem's level of difficulty which, subsequentially, was associated to a lower ability to solve AWPs accurately. These findings are relevant from a theoretical perspective since they provide an understanding of the mechanisms underlying the MA-performance link. Indeed, the mediation effect suggests that the tendency to worry about mathematics and numerical stimuli might influence task-specific metacognitive experiences, leading students to judge math-related tasks as more complex and demanding. The high perceived difficulty of the task is then likely to negatively affect students' expectancy of success (i.e., the higher the perceived difficulty, the lower students' likelihood to succeed; Eccles & Wigfield, 2020; Fulmer & Tulis, 2013), their interest and enjoyment (Fulmer & Frijters, 2011; Nuutila et al., 2021), and their self-regulation and strategy choices (Efklides, 2011), all of which would hinder their math performance (Nuutila et al., 2021). High evaluations of task difficulty are also linked to diminished willingness to engage with the task (Brehm & Self, 1989) and task avoidance (Atkinson, 1957). Additionally, some research has found that students evaluating a task as particularly difficult experience increased negative situational affect such as state anxiety, frustration, and stress (Pekrun et al., 2002; van Steensel et al., 2019). For instance, Hong (1999) found in a sample of university students that perceived difficulty of a statistics exam influenced test performance indirectly. Specifically, evaluations of test difficulty aroused feelings of worry and anxiety which then negatively impacted student performance. The perceived difficulty-state anxiety relationship is supported by a more recent work on reading tasks which showed that perceiving a task as demanding may result in higher situational negative affect (Fulmer & Tulis, 2013). To better understand the role of perceived task difficulty and emotional factors, future studies could investigate the relationship between stable affects (e.g., trait MA), situational affects (e.g., state MA), perceived task difficulty and math proficiency.

As to gender differences, results showed that in our sample girls reported higher levels of MA compared to boys, thus confirming the existence of gender differences in MA (Devine et al., 2012; Goetz et al., 2013; Jansen et al., 2016; Ferguson et al., 2015; Xie et al., 2019) and additionally suggesting that this gap may occur already in late primary school (Carey et al., 2017; Griggs et al., 2013; Hill et al., 2016; Szczygieł, 2019). A higher level of MA in girls might originate from several sources, including children's exposure to stereotypic beliefs and expectations (i.e., mathematics-gender stereotypes which state that mathematics is for men, not for women), and the influence and social transmission of anxiety by parents, teachers, and other significant adults (Luttenberger et al., 2018). For instance, it has been found that female teachers who are anxious about math are likely to influence girls, but not boys, in endorsing the traditional mathematics-gender stereotype (Beilock et al., 2010). Additionally, differences in MA between genders may be explained by the female tendency to be more open to reporting anxiety than men (Dowker et al., 2016). Future studies could advance our findings regarding gender differences in primary education by exploring the role of children's experience in the classroom or home environment. It must be noted that we found a medium effect size ($\eta_p^2 = .067$; Cohen, 1988) related to gender differences in MA. This implies that the gender gap in Grade 5 is still relatively modest, and it might increase over time, thus supporting meta-analytic findings on females being more prone to report MA during higher education compared to primary education (Else-Quest et al., 2010; Hembree, 1990). It should be recalled that in this study, a sample of Italian children was considered, and the present results on gender differences align well with similar Italian studies (e.g., Hill et al., 2016), however data are contrasting with some other European studies (e.g., Dowker et al., 2012), showing that cultural and stereotypic effects could contribute to the obtained results.

Our data did not support gender differences in AWP-solving performance, which is in line with previous research (Devine et al., 2012; Hill et al., 2016; Lindberg et al., 2010; Passolunghi et al., 2022), nor in the perception of problem's difficulty. The lack of gender differences in perceived difficulty could be explained by the fact that judgements of difficulty depend partly on objective difficulty cues (Vangsness & Young, 2018). Since boys and girls have been exposed to the same AWPs in class, they could be similarly (un)familiar with the task and therefore judge the difficulty level in the same way.

3.4.1 Limitations and Implications

Some limitations need to be acknowledged with respect to our study. First, we did not assess children's general anxiety nor test anxiety, which were observed to be related to both MA and math performance (Caviola et al., 2022; Donolato et al., 2020; Hembree, 1990). Therefore, our results should be interpreted with caution and future investigations should explore the specific role of MA on AWP-solving accuracy, after taking into account other forms of anxiety. Second, given the correlational nature of the current work, causation should not be inferred. Our study provided some evidence on the association between emotional and metacognitive factors, and the ability to solve AWPs, however further studies that examine those constructs longitudinally may help to make causal claims about this relationship.

Nevertheless, outcomes of the present study are relevant since they extend previous literature by showing the significant role of affective and metacognitive aspects in solving compare problems among primary school children. The findings demonstrate that feelings of anxiety toward math do not only have a direct effect on performance of an untimed problem-solving task but do also have an indirect effect through perception of the task difficulty. It is likely that individuals with high MA levels tend to view math-related tasks as more difficult and effort demanding. When a math task is evaluated as very difficult, success is believed to be impossible, and students could be willing to avoid or give up the task itself judging the effort not worthwhile (Atkinson, 1957). In this sense, it is possible that MA acts as an activator for negative on-task metacognitive and emotional states and in some cases leads to avoidance of math tasks as they are perceived to be too difficult. Therefore, recognizing MA and providing sufficient educational support in young students is crucial to prevent the development of avoidance of math tasks and math-intensive courses which might have lifelong effects (Ashcraft, 2002). As suggested by the present findings, this might be particularly important for girls, considering that they experience higher MA levels as early as the primary school. A strong MA manifestation could influence their future engagement in STEM careers (Levy et al., 2021), increasing the gender underrepresentation (Else-Quest et al., 2010; Wang & Degol, 2017) and shaping the stereotype that women are not suited to mathematics (Beilock et al., 2010). Children with high MA levels may benefit from interventions based on anxiety control strategies and self-efficacy beliefs (e.g., through exercising on diverse types of AWPs), which may lead to increased feelings of competence, a decrease in MA levels and, consequently, a reduction in perceived problem's difficulty (Passolunghi et al., 2020). However, literature on perceived difficulty in math educational settings is very limited and further investigations are needed.

In conclusion, the current work emphasizes the critical role of both emotional factors and metacognitive experiences in explaining individual differences in children's AWP-solving performance, as well as provides a deeper understanding of the non-cognitive mechanisms contributing to students' difficulties in math problem-solving. Additionally, the study confirmed the relevance of gender as another key individual characteristic, highlighting the need to consider gender differences in math learning within primary education.

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4. STUDY THREE

The Interplay between Ego-Resiliency, Math Anxiety, and Working Memory in Math Achievement [3]

Abstract

Previous research has suggested that math anxiety may contribute to poor math performance by interfering with working memory. However, only a limited number of studies have investigated the mediating role of working memory in the math anxiety-math performance link in school-aged children. Unlike math anxiety, ego-resiliency is a personality resource that promotes the management of challenges and has been positively associated with math performance and negatively with anxiety. Nevertheless, there is still limited understanding regarding the specific role of ego-resiliency in math learning and how it relates to math anxiety. This study aimed to investigate conjunctly the interplay between ego-resiliency, math anxiety, working memory, and performance on two different math tasks (i.e., arithmetic task and word problem-solving task), after controlling for general anxiety and age. The study involved 185 Italian children from grades 3 to 5. Serial multi-mediational analyses revealed that: (1) ego-resiliency has a positive indirect effect on math achievement through two paths—math anxiety, and math anxiety and working memory; (2) the study replicated previous findings showing that working memory partially mediated the relationship between math anxiety and math performance; (3) similar patterns of results were found for both math skills. The study identifies ego-resiliency as a possible protective factor in the development of math anxiety and suggests that ego-resiliency could be worth considering when designing interventions aimed at reducing negative emotions towards mathematics.

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[3] Adapted from Doz, E., Cuder, A., Pellizzoni, S., Grannello, F., & Passolunghi, M. C. (2024). The interplay between ego-resiliency, math anxiety and working memory in math achievement. *Psychological Research*. https://doi.org/10.1007/s00426-024-01995-0

4.1 Introduction

Mathematical skills represent one of the key competencies necessary for lifelong learning (European Parliament and the Council of European Union, 2006; Holmlund et al., 2018). Having adequate mathematical ability is necessary for a variety of academic and ordinary life situations, ranging from school examinations to managing personal finances and making career choices (Ansari et al., 2012; Kucian & von Aster, 2015). Yet, many students from primary school onwards manifest specific difficulties in this academic domain (Organization for Economic Cooperation and Development [OECD], 2013). Therefore, to foster a productive learning environment, it is essential to clarify how different factors may influence math performance.

Previous research has extensively investigated the detrimental effects of negative emotions, namely math anxiety (MA), on students' math achievement (Dowker et al., 2016). Studies conducted on adults indicated that MA would interfere with cognitive resources (i.e., working memory–WM) leading to poor math achievement (Eysenck & Calvo, 1992; Skagerlund et al., 2019). On the other hand, personal protective factors such as ego-resiliency (ER) have been found to support and sustain math learning in children (e.g., Donolato et al., 2019, 2020). In particular, ego-resilient pupils are better at adapting to stressful situations and managing emotions and worries, exhibiting therefore lower anxiety levels (Mammarella et al., 2018; Putwain et al., 2013). However, research has yet to consider how the interplay between ER, MA and WM influences math performance concurrently, especially in school-aged children who are in the process of learning mathematics. The effects of the abovementioned variables were vastly explored in relation to simpler arithmetic skills (such as calculation skills; see Cuder et al., 2023; Korem et al., 2022; Skagerlund et al., 2019; Soltanlou et al., 2019). Little is known about how ER, MA, and WM may differentially contribute to differences in proficiency in arithmetic word problem (AWP) solving, which is defined as the ability to solve math problems presented in a short narrative notation rather than in a numerical notation (Verschaffel et al., 2000). Indeed, the role of emotional, cognitive and temperamental factors for this kind of task, where the problem must be translated from a linguistic to a mathematical structure, are likely to be different from those invoked in basic arithmetic and procedural skills (Doz et al., 2023; Wu et al., 2017; Zhang et al., 2019). To fill these gaps, the present study aims to examine conjunctly the interrelated contributions of affective (i.e., MA), cognitive (i.e., WM), and temperamental (i.e., ER) factors on two different aspects of mathematics (i.e., arithmetic skills and AWP-solving) in primary school children. In the next paragraphs, we review relevant literature on the effect of MA on math achievement, the mediational role of WM in the MA-math performance link and, finally, the relationship between ER and mathematics.

4.1.1 Math Anxiety and Math Performance

As mentioned above, one of the most extensively studied emotional factors in math learning is MA. MA is commonly defined as a specific feeling of tension and anxiety that hinders the manipulation of numerical stimuli in everyday life and academic situations (Richardson & Suinn, 1972). While MA correlates with other forms of anxiety, such as general anxiety (Ashcraft & Moore, 2009; Donolato et al., 2020; Hart & Ganley, 2019) and test anxiety (Caviola et al., 2022; Cipora et al., 2022; Devine et al., 2012), it is regarded as a distinct and specific construct (Kazelskis et al., 2000; Mammarella et al., 2018).

A substantial body of research has demonstrated the detrimental impact of MA on math achievement: highly math-anxious individuals tend to make more errors on math tasks and/or take longer to respond than individuals with low MA (for reviews, see Barroso et al., 2021; Caviola et al., 2022). Notably, some studies suggest the existence of a negative correlation between MA and math attainments as early as in primary school children (e.g., Ramirez et al., 2013; Sorvo et al., 2019; Szczygieł, 2021). This is a significant concern since the development of MA in early school years can lead to avoidance of future math-intensive activities and make the acquisition of mathematical skills more difficult, further exacerbating negative emotions (Ashcraft, 2002; Szczygieł, 2020). Thus, more research is needed to elucidate the role and mechanisms of MA, specifically in primary school students.

4.1.2 Math Anxiety, Working Memory and Math Performance

Although the influence of MA on math performance has been consistently demonstrated, the mechanisms underlying this relationship are not completely clear. Thus far, WM has been the most studied factor that could account for how MA may influence math performance (Ashcraft & Kirk, 2001; Justicia-Galiano et al., 2017). WM is defined as a limited capacity cognitive system that allows individuals to hold and simultaneously manipulate information over brief periods of time (Baddeley, 1986; Baddeley & Hitch, 1974). According to the classic multicomponent model (Baddeley, 2000; Baddeley & Hitch, 1974), WM is described by: (1) a verbal WM subsystem, which is responsible for the temporary storage of verbal information, such as words and numbers; (2) a visuo-spatial WM subsystem, which allows the temporary storage of visual and spatial information, such as colours, figures and positions in space; and (3) the central executive, which is involved in regulating, manipulating, and processing the stored verbal and visuo-spatial information. More recently, Baddeley (2000) added to the model the episodic buffer, which is characterized by multidimensional storage that forms an interface between the subsystems of WM, long-term memory and the central executive. However, the episodic buffer is less studied in developmental samples (Wang et al., 2015).

WM plays a pivotal role in math achievement (for a review, see Peng et al., 2016), since solving math tasks requires applying multiple procedures, storing intermediate computational results and/or numerical information, as well as remembering task rules. Recent research suggests that visuo-spatial WM is particularly relevant to math learning, while verbal WM is more closely associated with reading attainment (Giofrè et al., 2018). Moreover, during primary school years, visuo-spatial WM becomes especially important for tackling new and complex math tasks (e.g., Ashkenazi et al., 2013; Li & Geary, 2013; Szűcs et al., 2014), serving as a reliable predictor of math performance (Allen & Giofrè, 2021; Liang et al., 2022). Given the above-mentioned evidence, in our study we decided to focus on the visuo-spatial WM component.

According to the Processing Efficiency Theory proposed by Eysenck and Calvo (1992), emotional and cognitive factors interact. In particular, anxiety generates worries and intrusive thoughts, which may overload WM resources and, consequently, disrupt concurrent task performance (Ashcraft & Krause, 2007). Therefore, WM would mediate, at least partly, the MA-math performance link. Studies involving adult populations generally confirm the Processing Efficiency Theory and the mediating role of WM (e.g., Ashcraft & Kirk, 2001; DeCaro et al., 2010; Ganley & Vasilyeva, 2014; Miller & Bichsel, 2004; Skagerlund et al., 2019). Support for this theory is also provided by recent meta-analytic findings that show a negative correlation between MA and WM capacity ($r = -.168$) and find that WM mediates the relationship between MA and math performance with a mean effect size of −0.092 (Finell et al., 2022). However, research on school-aged children remains relatively limited (Justicia-Galiano et al., 2017; Pellizzoni et al., 2022; Szczygieł, 2021). For instance, Živković et al. (2023) investigated the mediating role of WM and self-competence in the relationship between MA and arithmetic reasoning in students from third, fifth and seventh grades. They have found that MA affected the visuo-spatial WM component, which subsequently influenced students' math performance. Similar results were obtained by Soltanlou et al. (2019), who examined the relationship between MA, WM and multiplication learning in fifth graders using an intervention paradigm. Nevertheless, it must be noted that the majority of these studies on school-aged children (i.e., Soltanlou et al., 2019; Szczygieł, 2021; Živković et al., 2023) did not control for children's general anxiety, which has been found to be related to MA sharing a moderate amount of variance (see Donolato et al., 2020; Hembree, 1990; Luttenberger et al., 2018). Understanding the unique impact of MA on WM in primary school children is crucial from both a theoretical and practical perspective. Therefore, more studies investigating this relationship in developmental samples, while considering students' general anxiety, is needed.

4.1.3 Ego-Resiliency and Math Performance

In contrast to MA–which disrupts math performance–children possess several personal assets that sustain positive outcomes in their personal, social, and academic life domains (Eisenberg et al., 1997; Masten, 2001). Among these, ER is considered to play a key role (Donolato et al., 2020). ER refers to a temperamental or personality resource that allows individuals to be flexible and resourceful in adapting to external and internal stressors and recover quickly from day-to-day adversities (Block & Block, 1980; Caspi & Silva, 1995; Fletcher & Sarkar, 2013). Thus, resilient people can maintain or rapidly return to their prior level of functioning after confronting a stressful situation (Block & Block, 2006) and therefore avoid negative (emotional, motivational or cognitive) consequences.

In the school environment, students frequently experience some level of challenge, adversity or pressure, such as evaluative stress, scarce performance, demanding tasks, and difficulties in understanding concepts. This could be particularly true for mathematics, which is considered a complex school subject, and often reported as one of the most demanding, stressful and strenuous in the school curricula (Ashcraft et al., 2007; Ashcraft & Ridley, 2005). According to the definition given above, ER could be a relevant personal resource for managing school challenges and emotional difficulties during math learning (Alessandri et al., 2017). In this respect, several studies have reported a positive association between students' ER and math achievement supporting the conviction that amongst children of similar math ability, ego-resilient individuals perform challenging math tasks better (Alessandri et al., 2017; Donolato et al., 2019, 2020; Kwok et al., 2007; Putwain et al., 2013).

According to the theoretical conceptualization of ER proposed by Block and Block (1980, 1996), ego-resilient individuals experience lower levels of anxiety or other negative affects since they are able to maintain a sufficient adaptational system and are better at emotional regulation (Eisenberg et al., 2011; Lee & Johnston-Wilder, 2017; Martin & Marsh, 2006). Supporting this theoretical perspective, literature has shown a negative association between ER and general anxiety (Block & Gjerde, 1990; Chuang et al., 2006; Donolato et al., 2020; Huey & Weisz, 1997). For instance, Mammarella et al. (2018) employing a latent profile analysis, found that primary school children with a low anxiety risk profile (general anxiety, test anxiety and math anxiety) scored higher on resilience than those at higher risk for anxiety. These findings suggest that ER could act as a protective factor in the development of various forms of anxiety. Accordingly, Putwain et al. (2013) examined whether test anxiety mediated the relationship between ER and test performance (in math and English) in primary school children, after controlling for their prior abilities. The authors found a significant indirect effect of resilience on test performance through test anxiety. That is, students with high ER experienced lower test anxiety and therefore performed better than their less resilient counterparts who experienced greater test anxiety. A similar mediating mechanism could be hypothesized with other specific forms of anxiety, such as MA: ER might positively impact math achievement by boosting students' ability to manage MA (Lee & Johnston-Wilder, 2017). However, to the best of our knowledge no study has examined the mediating role of MA in the ER-math performance relationship in primary school children.

4.1.4 The Present Study

Considering the scarce findings on the topic, the main aim of this study was to investigate the simultaneous role of ER, MA and visuo-spatial WM on primary school children's math achievement on two different tasks (arithmetic skills and AWP-solving), while controlling for general anxiety and age. Specifically, a theory-based serial multi-mediational model (see Figure 4.1) was tested to verify if the relationship between ER and math performance is serially mediated by MA (first mediator) and visuo-spatial WM (second mediator). Involving multiple mediators may better explain how the interplay between different variables influences students' math attainments (Hayes, 2013; Justicia-Galiano et al., 2017).

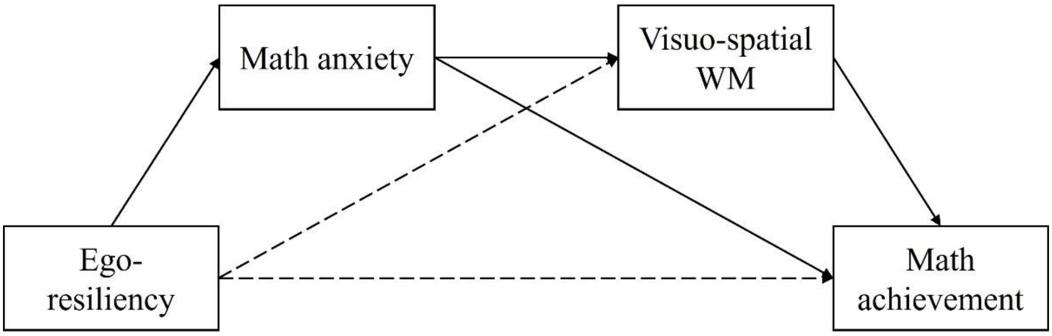
Based on Block & Block's (1980) theory and more recent evidence that demonstrates how ego-resilient children show greater emotional management and lower anxiety levels (e.g., Donolato et al., 2019; Mammarella et al., 2018; Putwain et al., 2013), we expected ER to be negatively related to MA. MA would then have both a direct (Pellizzoni et al., 2022; Skagerlund et al., 2019;

Wu et al., 2017) and an indirect negative effect through visuo-spatial WM on math performance (Finell et al., 2022; Živković et al., 2023).

As previously mentioned, two different types of math skills were included as dependent variables given that the majority of existing studies focused on simple arithmetic tasks (Commodari & La Rosa, 2021; Soltanlou et al., 2019; Živković et al., 2023), neglecting other more complex and demanding math abilities such as AWP-solving (Doz et al., 2023; Gilmore, 2023; Passolunghi et al., 2019; Wu et al., 2017). In order to investigate the possible different contribution of temperamental, emotional and cognitive factors on different tasks, our study aimed to further previous research by taking into consideration both math skills, i.e. arithmetic skills and AWP-solving.

Figure 4.1

Illustration of the Hypothesized Theory-Based Serial Multi-Mediational Model



Note. The model assumes indirect effects from ego-resiliency to math achievement through (1) math anxiety and (2) math anxiety and WM. The dashed lines represent hypothesized non-significant relations. WM = working memory.

4.2 Method

4.2.1 Participants

A total of 221 third, fourth and fifth-grade children attending five public primary schools located in northeast Italy were enrolled in the study. Only typically developing children were considered for the subsequent analysis. Therefore, 19 participants with special educational needs, intellectual disability or neurological or genetic disorders were excluded from the sample. Six participants were excluded from the analysis due to missing data (they were absent on at least one of the testing sessions). One participant produced outlier scores regarding math anxiety levels and was handled with listwise deletion and removed from the analysis. Thus, the final sample analysed in this study consisted of 185 children (102 girls, 83 boys) with a mean age of 9.47 years (*SD* = 0.88, min = 8, max = 11). All students were Caucasian, and their socio-economic status was mainly middle class, established on the basis of school records. All the students were native Italian speakers or fluent in Italian. For sample size estimation, an a priori power analysis was conducted using a simulation method in R, version 4.2.3 (R Core Team, 2020). Results indicated that the minimum sample size needed to achieve statistical power of .80 for detecting the hypothesized indirect effect, at a significance criterion of α = .05, was N = 181. Thus, our sample size of N = 185 is adequate.

The study received approval by the ethical committee of the University of Trieste and was conducted in compliance with the Declaration of Helsinki, the ethical guidelines of the Italian Association of Psychology and the ethical code of the Italian Register of Professional Psychologists. Written informed parental consent was obtained before assessing the students. All children participated voluntarily and received a small gift (i.e., a sticker collection) as an appreciation for their participation.

4.2.2 Measures

Ego-Resiliency

Ego-resiliency was measured using the *Ego Resiliency Scale* (ER89; Block & Kremen, 1996; Italian adaptation by Donolato et al., 2019). This is a questionnaire consisting of 14 statements (e.g., “I quickly get over and recover from being startled”). Participants were asked to indicate on a 4-point Likert scale (1= *does not apply at all*; 4= *applies very strongly*) the degree to which they agree to each item. The total score could range from 14 to 56, with higher scores indicating greater ER. The reliability of the questionnaire in the present sample was adequate (Cronbach’s α = .75).

Math Anxiety

The *Abbreviated Math Anxiety Scale* (AMAS; Hopko et al., 2003; Italian adaptation for primary school children by Caviola et al., 2017) was used to evaluate children's level of MA. AMAS is a brief questionnaire that comprises nine statements describing different situations involving mathematical activities (i.e., math learning and math testing). Children had to determine how anxious they would feel in each depicted situation, using a 5-point Likert scale (1= *a little anxious*; 5= *extremely anxious*). The total score could range from 9 to 45, with higher scores indicating higher levels of MA. In the present sample, a good reliability of the scale was observed (Cronbach's α = .83).

General Anxiety

The *Revised Children's Manifest Anxiety Scale-Second Edition* (RCMAS-2; Reynolds et al., 2012) is a self-report questionnaire used to assess general anxiety in children and adolescents aged 6-19. In the present study, the Short Form of the RCMAS-2 was employed. It consists of 10 items (e.g., "I feel someone will tell me I do things the wrong way") to which children must respond with a yes/no response format. The total score could range from 0 to 10 with higher scores corresponding to higher levels of general anxiety. The reliability of the scale was good in the present sample (polychoric Cronbach's α = .72).

Visuo-Spatial Working Memory

We administrated a computerized adaptation of the *Visual Pattern Test–Active Version* included in the standardized Italian BVS-Corsi battery (Mammarella et al., 2008). This task tests the ability to simultaneously retain and actively manipulate visuo-spatial information (Giofrè et al., 2013). The measure included twenty-one matrices of increasing size (from 4 to 16 squares) presented on a computer screen. Matrices were composed of white and coloured cells (the smallest had 4 total squares and 2 coloured cells, the largest had 16 total squares and 8 coloured cells). Each matrix was presented to the participants for 3 seconds, then it disappeared. Children were asked to mark on a blank matrix of the same size the location of the coloured cells moved by one row below (e.g., if the coloured cell was presented in the first row of the matrix, children had to mark the cell in the second row). Therefore, children were required to mentally shift the presented pattern one line below. The last row in the presentation matrix was always empty. Three matrices were presented for each level (span) of complexity, and a span was considered correct when a participant was able to correctly reproduce at least two of the three matrices for a given level. The final score was the maximum span level obtained (range from 2 to 8). Before administering the task, participants were given three practice trials with feedback. Task reliability was very good (Cronbach's α = .90).

Math Performance

In order to evaluate the students' math abilities, we considered two different mathematical sub-domains: arithmetic skills and AWP-solving. Arithmetic skills, which encompass calculation ability as well as the understanding of mathematical symbols and the meaning of mathematical operations (Bisanz et al., 2005), were measured using three paper-pencil subtests drawn from the standardized Italian battery *ACMT 3 6-14* (Cornoldi et al., 2020): Math fluency, Inferences and Number matrices. The Math fluency subtest evaluates a student's ability to calculate basic arithmetic problems quickly and accurately. It requires solving 15 arithmetic operations (additions for third graders; additions and subtractions for fourth graders; additions, subtractions and multiplications for fifth graders) as quickly as possible in one minute. The Inference subtest assesses arithmetic reasoning skills and comprises 12 items divided into three different types of tasks that must be completed in two minutes: in the first task participants had to solve 4 arithmetic operations involving images, in the second task they were asked to complete 4 operations by inserting the corresponding missing sign (+, -, ×, :), and in the third task they had to solve 4 operations by using the result of another similar operation as a cue. The Number matrices subtest assesses children's arithmetic skills and math reasoning using numerical series. The participants have two minutes to solve 12 incomplete numerical matrices with the correct number. Responses were awarded a score of 0 or 1, depending on whether they were incorrect or correct, respectively. The final score consisted of the sum of all correct responses and could range from 0 to 39. Cronbach α in the present sample was .84.

To assess children's AWP-solving skills, we administrated a task (adaptation from Hegarty et al., 1992; see Doz et al., 2023) consisting of 8 word problems, which required one or two elementary arithmetic calculations (addition and subtraction) to be solved. All the word problems included a relational term, such as *more than* or *less than*, and were similar to those assigned by teachers to students at the considered school grade. An example of word problems presented to third graders is: "At Bang-Bang, a teddy bear costs €18. This is €3 more than the same teddy bear on Aliexpress. How much does the teddy bear cost on Aliexpress?". The order of the problems was randomized. The score of 0 or 1 was attributed to each problem according to whether the answer was wrong or correct, respectively. Its measurement range was between 0 and 8. Cronbach's α in the present study was .82.

4.2.3 Procedure

Participants were tested in three sessions administrated at school. Depending on the school schedule and the children's availability, the sessions were separated by 7 to 10 days. The first session included the evaluation of students' ER, MA and general anxiety. In the second session, participants were tested on visuo-spatial WM. In the final session, arithmetic skills and AWP-solving ability were assessed. Each session lasted approximately 30 to 40 minutes. Data were collected by trained researchers.

4.3 Results

Statistical analyses were performed with SPSS software, version 28. Descriptive statistics (means and standard deviations) and correlations for all variables are reported in Table 4.1. It can be noted that both math tasks (arithmetic task and AWP-solving task) were significantly and positively correlated with ER and visuo-spatial WM task, but negatively with MA. Noteworthy, ER was statistically significantly and negatively correlated with MA and general anxiety. A statistically significant negative correlation emerged between MA and visuo-spatial WM.

Table 4.1

Descriptive Statistics and Bivariate Correlations Between All Variables

Measure	*M*	*SD*	1.	2.	3.	4.	5.	6.	7.
1. Ego-resiliency	42.40	6.30	—						
2. Math anxiety	21.86	6.83	–.42**	—					
3. General anxiety	3.51	2.19	–.22**	.39**	—				
4. Visuo-spatial WM	4.63	1.83	.10	–.23**	–.03	—			
5. Arithmetic skills	17.76	5.75	.16*	–.33**	–.14	.33**	—		
6. AWP-solving	2.72	1.33	.17*	–.22**	–.12	.28**	.35**	—	
7. Age	9.47	.88	.02	–.10	.14	.24**	.15*	–.09	—

Note. WM = working memory; AWP-solving = arithmetic word problem-solving.

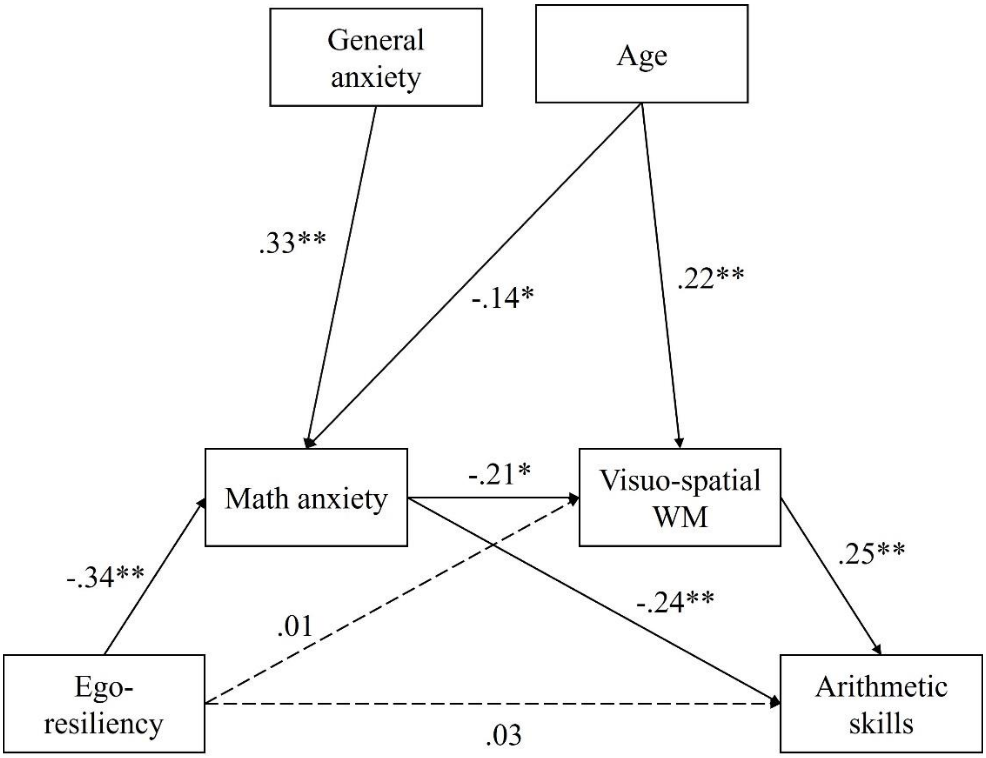
* $p < .05$, ** $p < .01$.

Since the correlations between the variables of interest resulted statistically significant, we proceeded by testing the hypothesized serial multi-mediational model. Model 6 of the SPSS PROCESS macro was utilized (Hayes, 2017). 5000 bootstrap samples were employed to generate 95% bias-corrected and accelerated confidence intervals; if the 95% confidence interval of the indirect effect excludes zero, significance of the effect can be assumed (Hayes, 2017).

First, a serial mediation model was calculated placing ER as the focal regressor, arithmetic skills as the dependent variable, MA as the first serial mediator and visuo-spatial WM as the second mediator. General anxiety and age were inserted as covariates. The results of the multiple-mediation model are presented in Figure 4.2. Findings revealed that ER was statistically significantly and negatively related with MA ($\beta = –.343$, s.e. = .069, $p < .001$), but was not associated with visuo-spatial WM (*β* = .013, s.e. = .022, *p* = .861). In the second step, findings showed that MA was significantly and negatively associated with visuo-spatial WM (*β* = –.212, s.e.= .022, *p* = .011). Finally, MA was negatively associated with arithmetic skills (*β* = –.238, s.e. = .068, *p* = .003), whereas visuo-spatial WM was positively related to arithmetic skills (*β* = .252, s.e. = .223, *p* < .001).

Figure 4.2

Results of the Serial Multi-Mediation Analysis With Arithmetic Skills As the Outcome Variable



Note. R^2 = .188 Ego-resiliency was inserted as the focal regressor, math anxiety as the first mediator, visuo-spatial WM as the second mediator and arithmetic skills as the outcome variable. General anxiety and age were inserted as covariates. The figure shows the standardized regression coefficients, *β*. The dashed lines represent non-significant coefficients. WM = working memory.

* *p* < .05, ** *p* < .01.

To estimate confidence intervals of the indirect effects, we used the bias-corrected bootstrapping procedure. Using 5000 bootstrapped samples, two statistically significant indirect effects of ER on arithmetic performance were observed (see Table 4.2): (1) through MA (IE = 0.082, bootstrap s.e. = 0.033, 95% bias-corrected CI [0.022, 0.154]) and (2) through MA and visuo-spatial WM (IE = 0.018, bootstrap s.e. = 0.009, 95% bias-corrected CI [0.003, 0.041]). In other words, children's ER impacted MA, which in turn had both a direct and indirect effect through visuo-spatial WM on arithmetic skills.

Table 4.2

Direct and Indirect Effects of Ego-Resiliency on Arithmetic Skills

Path	Standardized effect	Bootstrap s.e.	95% bias-corrected CI	
			Lower limit	Upper limit
Direct effect				
ER → arithmetic skills	0.030	0.067	–0.104	0.164
Indirect effects				
ER → MA → arithmetic skills	**0.082**	**0.033**	**0.022**	**0.154**
ER → visuo-spatial WM → arithmetic skills	0.003	0.021	–0.039	0.046
ER → MA → visuo-spatial WM → arithmetic skills	**0.018**	**0.009**	**0.003**	**0.041**

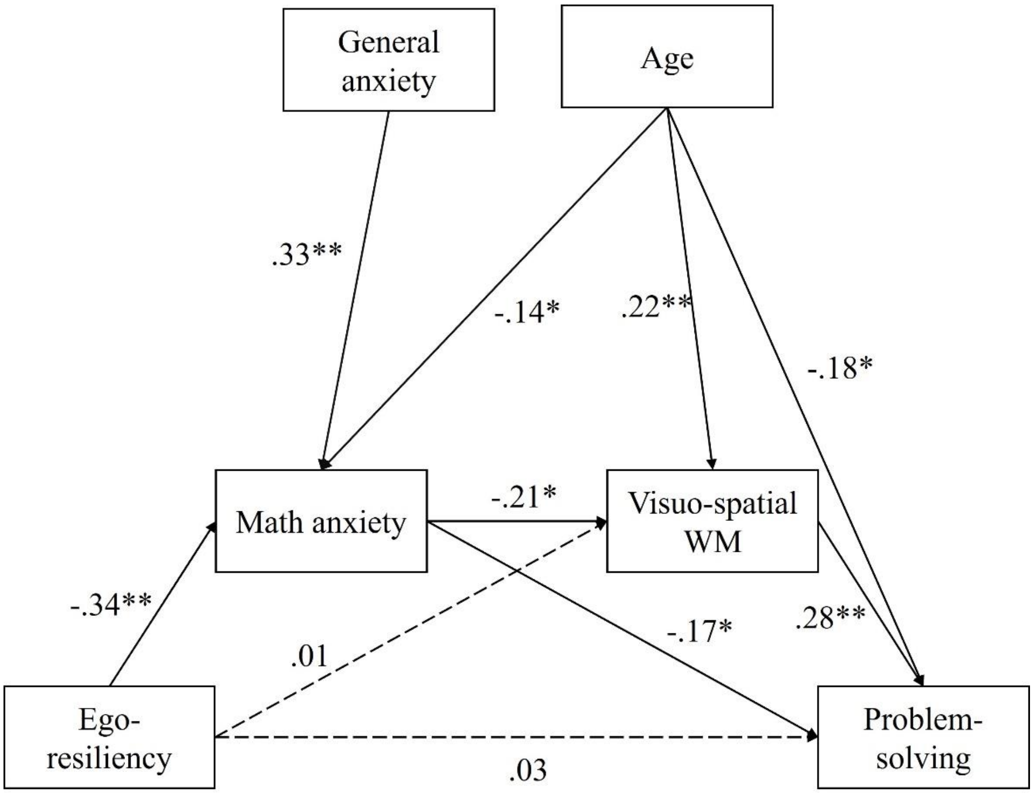
Note. ER = ego-resiliency; MA = math anxiety; WM = working memory; CI = confidence interval. Statistically significant effects are shown in bold.

A second serial mediation model was calculated placing ER as the focal regressor, AWP-solving accuracy as the dependent variable, MA as the first mediator and visuo-spatial WM as second mediator. The results of the second mediation model are presented in Figure 4.3. Findings revealed that ER was statistically significantly and negatively related with MA (β = –.343, s.e. = .069, p < .001), but was not associated with visuo-spatial WM (β = .013, s.e. = .022, p = .861). MA was significantly and negatively associated with visuo-spatial WM (β = –.212, s.e.= .022, p = .011).

Moreover, MA was negatively associated with problem solving performance (*β* = –.173, s.e. = .028, *p* = .040), and visuo-spatial WM (*β* = .283, s.e. = .093, *p* < .001) was positively associated with AWP-solving performance. ER was not significantly associated with AWP-solving outcome (*β* = –.032, s.e. = .028, *p* = .680).

Figure 4.3

Results of the Serial Multi-Mediation Analysis With AWP-Solving Achievement As the Outcome Variable



Note. R^2 = .135 Ego-resiliency was inserted as the focal regressor, math anxiety as the first mediator, visuo-spatial WM as second mediators and word problem-solving achievement as the outcome variable. General anxiety and age were inserted as covariates. The figure shows the standardized regression coefficients, *β*. The dashed lines represent non-significant coefficients. WM = working memory.

* *p* < .05, ** *p* < .01.

Using 5000 bootstrapped samples, two statistically significant indirect effects of ER on AWP-solving performance were observed (see Table 4.3): (1) through MA (IE = 0.022, bootstrap s.e. = 0.011, 95% bias corrected CI [0.001, 0.046]) and (2) through MA and visuo-spatial WM (IE = 0.006, bootstrap s.e. = 0.004, 95% bias-corrected CI [0.001, 0.015]). To put differently, ER impacted MA levels, which in turn had both a direct and indirect effect through visuo-spatial WM on AWP-solving performance. In summary, the data show similar results for arithmetic skills and AWP-solving.

Table 4.3

Direct and Indirect Effects of Ego-Resiliency on AWP-Solving Performance

Path	Standardized effect	Bootstrap s.e.	95% bias-corrected CI	
			Lower limit	Upper limit
Direct effect				
ER → AWP-solving	–0.017	0.028	–0.067	0.044
Indirect effects				
ER → MA → AWP-solving	**0.059**	**0.030**	**0.002**	**0.121**
ER → visuo-spatial WM → AWP-solving	0.003	0.023	–0.045	0.048
ER → MA → visuo-spatial WM → AWP-solving	**0.020**	**0.010**	**0.003**	**0.046**

Note. ER = ego-resiliency; MA = math anxiety; WM = working memory; AWP-solving = arithmetic word problem-solving; CI = confidence interval. Statistically significant effects are shown in bold.

4.4 Discussion

Much of the previous research has examined the relationship between temperamental, emotional, and cognitive factors and math achievement in isolation (e.g., Alessandri et al., 2017; Kwok et al., 2007; Zheng et al., 2011). With this work we aimed to adopt a more holistic perspective and advance knowledge of how multiple factors – ER, MA and WM – can interact and determine math performance among primary school children. Thus, the primary purpose of this study was to provide a comprehensive model of the links between ER, MA, WM and math performance. In particular, we were interested in verifying a theoretically based serial mediational model (Block & Block, 1980; Eysenck & Calvo, 1992) in which we hypothesized that the relationship between ER and math performance would be serially mediated by MA (first mediator) and WM (second mediator). Secondly, we sought to comprehend whether the tested factors could differently contribute to explain individual differences in different types of math skills (i.e., arithmetic skills and AWP-solving ability). Moreover, the current study advances previous studies by controlling for general anxiety and age, which are important factors to consider in children's math learning (Donolato et al., 2020).

Our analysis has revealed three main findings: (1) ER indirectly impacted math achievement through MA, and MA and visuo-spatial WM; (2) we replicated previous findings showing that visuo-spatial WM partially mediates the relationship between MA and math performance; (3) results were similar for arithmetic skills and AWP-solving ability.

4.4.1 The Effect of ER Is Mediated by MA and WM

The results from this study clarify the role of ER in math achievement, a topic that has not been adequately addressed by previous empirical works. Firstly, in accordance with existing literature (Alessandri et al., 2017; Donolato et al., 2019, 2020; Kwok et al., 2007; Putwain et al., 2013), children's ER was found to be positively correlated with math achievement, assessed with an arithmetic task and an AWP-solving task. This finding is consistent with the argument that being resilient, and thus being able to flexibly adapt when challenged or under pressure, supports school success in mathematics (Lee & Johnston-Wilder, 2017).

Secondly, serial mediational analyses revealed that the relationship between ER and math achievement was indirect. Consistent with our hypothesis, ER was negatively associated with MA, which, in turn, negatively impacted math performance both directly and indirectly through visuo-spatial WM. This finding aligns with previous research demonstrating a negative relationship between ER and negative emotions (Chuang et al., 2006; Donolato et al., 2019, 2020; Putwain et al., 2013), and suggesting ER as a personal protective factor in anxiety development (Mammarella et al., 2018). Our study emphasizes the importance of ER specifically within the context of math anxiety. The data suggest that the trait of ER may facilitate individuals in adapting to situations when mathematics becomes difficult and challenging. In fact, although all children may experience difficulties while learning mathematics, higher ER levels can promote emotional regulation (Eisenberg & Morris, 2002) and perseverance (Borman & Overman, 2004), thus leading to reduced anxiety (Tellegen, 1985) and better academic performance (Putwain et al., 2013). On the other hand, lower levels of ER can be associated with diminished adaptability, difficulty responding to changing circumstances, a tendency to become disorganized under stress, and poor recovery after distressing experiences (Eisenberg & Morris, 2002). These factors can contribute to perceiving mathematics as a fearful subject and, over time, develop higher levels of MA. Therefore, our results support the theoretical model viewing ER as a construct closely related to the ability to flexibly regulate emotions (Block & Block, 1980; Eisenberg et al., 2011).

It must be noted, however, that our results are partly in contrast with those found by Donolato et al. (2020). The authors assessed 5th to 8th graders on MA, general anxiety, test anxiety, ER and math achievement and found that ER was negatively associated with general anxiety, but not with test anxiety or MA. A possible explanation for these contrasting results could be referred to the participants' ages (Chuang et al., 2006; Gjerde et al., 1986). In fact, pre-adolescence represents a critical period when students start to engage with increasingly more demanding mathematical activities and experience increased general anxiety (Karande et al., 2018). Moreover, it should be noted that they are also more sensitive in evaluating their symptoms of anxiety compared to younger children. Therefore, future investigations should consider studying the ER-MA relationship in samples of different age or evaluating this relationship longitudinally.

4.4.2 WM Mediates the MA-Math Performance Link

A second significant finding of the present study is that visuo-spatial WM partially mediated the MA-math performance link, for both math tasks, also after controlling for the influence of general anxiety and age. This finding is in accordance with previous studies among primary school children, indicating that MA negatively impacted students' math achievement both directly and indirectly through visuo-spatial WM (e.g., Soltanlou et al. 2019; Živković et al., 2023). This aligns with the Processing Efficiency Theory (Eysenck & Calvo, 1992) and highlights that the interplay between emotional and cognitive factors may occur in school-aged children (Justicia-Galiano et al., 2017; Soltanlou et al., 2019; Szczygieł, 2021), mirroring patterns observed in older students and adults (Ashcraft & Kirk, 2001; De Caro et al., 2010; Ganley & Vasilyeva, 2014; Miller & Bichsel, 2004; Skagerlund et al., 2019). Specifically, children with higher levels of MA may experience more worries and intrusive thoughts, thereby occupying WM resources and limiting storage capacity for visual and spatial information, which is essential to solve a variety of math tasks. In the context of AWP-solving, WM plays a critical role. Solving AWPs typically requires translating verbal information into mathematical representations, constructing a mental model of the problem situation, performing mental calculations, and generating effective problem-solving strategies (Hegarty et al., 1992; Mayer & Hegarty, 1996). Each of these processes relies heavily on WM resources (Lee et al., 2009; Peng et al., 2016). Among the different components of WM, visuo-spatial WM is particularly crucial, as it aids in the mental manipulation of visual representations involved in solving AWPs. This function may be especially relevant for the word problems in the current study, which require comparing numerical quantities (Lewis, 1989). In such cases, participants may rely on visuo-spatial WM to create and manipulate a mental representation of the problem, allowing them to spatially compare the quantities involved (Mayer & Hegarty, 1996). Moreover, visuo-spatial WM has been shown to support not only problem representation but also arithmetic reasoning and calculation (Kyttälä & Lehto, 2008).

It is important to note that MA also exhibited a direct negative relationship with math performance, suggesting the presence of additional mechanisms through which MA hinders students' achievements. Recent studies posit that MA may influence students' self-regulated learning and avoidance behaviours. For instance, research suggests that students with high MA perceive mathematical tasks as more challenging (Doz et al., 2023) and exhibit a reduced level of perseverance when faced with mathematical difficulties (Gabriel et al., 2020; Yu et al., 2021), which may negatively influence a student's effort and overall performance.

4.4.3 Different Math Tasks

Lastly, the study sought to better comprehend whether temperamental, emotional, and cognitive factors would play the same role in two different types of math skills (i.e., arithmetic skills and AWP-solving ability). Our findings indicated a consistent pattern across both math skills. This is, ER was indirectly related to both arithmetic skills and AWP-solving performance through MA and MA and visuo-spatial WM. It can be noted, however, that MA exhibited a stronger overall negative correlation ($r = -.33$) and a stronger direct relationship ($\beta = -.24$) with the arithmetic task compared to the AWP-solving task ($r = -.22$; $\beta = -.17$). One possible explanation for this disparity could be attributed to the inherent complexity of AWP-solving (Duque de Blas et al., 2021; Passolunghi et al., 2022), a task that heavily relies on WM (Fuchs et al., 2020; Peng et al., 2016) and as such most of the negative effect of MA may passes through its interplay with WM. Further research could explore this hypothesis by manipulating the complexity of the math tasks.

A second difference relates to age, which was directly and positively associated with AWP-solving performance but not with performance on the arithmetic task. This effect can be attributed to the different cognitive demands of the two tasks. AWPs require not only the ability to perform calculations but also the capacity to interpret and integrate verbal information, construct a coherent mental model of the problem, and determine the appropriate arithmetic operations (Mayer & Hegarty, 1996). This task engages higher-order cognitive processes, such as language comprehension, executive functions, and reasoning abilities, all of which tend to develop with age (Passolunghi et al., 2022; Swanson et al., 2013). As children grow older, they become more proficient at integrating these skills, which directly enhances their ability to solve AWPs. In contrast, basic arithmetic tasks, such as simple addition, subtraction or multiplication, rely more heavily on rote memory and retrieval of math facts (Geary, 2004). These skills are often developed through repeated practice and memorization, and once acquired, they become less sensitive to age-related improvements in cognitive abilities like language comprehension or executive functions.

It is also important to note that the explained variance by the variables included in our models varies between the two types of math skills. Specifically, the model explains a higher percentage of variance in arithmetic skills (19%) compared to AWP-solving (13.5%), suggesting that additional variables may be relevant especially in accounting for AWP-solving performance (see Fuchs et al., 2017; Lin, 2021). One such variable, not included in the current study, is verbal WM (Pina et al., 2014). Previous research has extensively shown that solving AWPs relies not only on visuo-spatial WM but also significantly on verbal WM, as the task requires the maintenance and manipulation of words (Fuchs et al., 2020; Fung & Swanson, 2017; Lee et al., 2004; Peng et al., 2016; Zheng et al., 2011). A second crucial variable, that could explain the difference in the explained variance, is language ability and text comprehension (Boonen et al., 2014; Cartwright et al., 2022; Fuchs et al., 2015; Passolunghi et al., 2022). In their longitudinal study, Fuchs et al. (2017) found that start-of-year language skills predicted second graders' year-end word problem-solving ability more strongly than calculation ability, while initial arithmetic skills predicted year-end calculations more strongly than word problem-solving, suggesting that word problems and calculations may represent "distinct domains of academic performance" (p. 10). In accordance with this finding, our study highlights the importance of investigating specific math abilities separately, as each may exhibit unique characteristics and may involve different processes.

4.4.4 Implications

Taken together, by adopting a holistic perspective the study highlights how temperamental, emotional, and cognitive factors interact to shape children’s math performance. Particularly, the results highlight the value of ER as a predictor of lower MA and, consequently, higher math performance, underlining the important and non-negligible role that personal assets have in math learning. These findings have significant implications in the educational setting, especially when developing school interventions aimed at enhancing math abilities and reducing negative attitudes toward math in primary education. Although most of the resilience programs introduced in schools had the scope of enhancing student mental health (e.g., Brunwasser et al., 2009), the results of this study indicate that interventions on ER might also have practical benefits for coping with specific negative emotions toward mathematics. Therefore, in addition to the traditional exercises used to reduce MA (e.g., Passolunghi et al., 2020; Samuel & Warner, 2019), novel MA interventions could involve activities related to the enhancement of ER. Such school-based programs could incorporate activities and metacognitive discussions that foster perseverance, effort, and strategic thinking, as well as include diagnostic feedback, guidance on seeking assistance and support in math learning, and encourage students to view mistakes as opportunities for growth rather than failures (Lee & Johnston-Wilder, 2017).These school programs could also focus on fostering classroom collaboration and help students define success and competence in relation to personal objectives and values instead of competing with others (Martin & Marsh, 2006). Finally, such programs could be offered in parallel with more specific math training, which is generally targeted on improving math skills and their underlying cognitive processes. Indeed, the latter might be ineffective if children do not learn how to handle their negative emotional states or are not resilient enough.

4.4.5 Limitations and Future Directions

Some limitations should be taken into account when interpreting the present results. Firstly and most importantly, the serial mediation analysis relies on correlational procedures and, as such, causal relations should not be inferred. Our study provided some evidence on the association between temperamental, affective and cognitive factors, and math abilities. However, longitudinal studies are needed to accurately determine the direction and temporal relation of the links between the different variables involved. For instance, recent studies suggest that the relationship between MA and math performance is reciprocal: Pekrun et al. (2023) investigated within-person relationships regarding student achievement and emotions in mathematics over 5 school years and found that achievement negatively predicted negative emotions, and these emotions, in turn, were negative predictors of math achievement. Similarly, as pointed out by Putwain et al. (2013), it is likely that the constructs of ER and MA could also interplay reciprocally over time, so future research may consider employing a longitudinal approach to establish evidence for the causal relationship between ER and MA. Another limitation of the current work is its reliance on individual tasks, which are recognized as reliable, but may not capture the full complexity of the constructs under investigation. Future research could benefit from utilizing more tasks and structural equation modeling to provide a more comprehensive analysis. Finally, we did not control for children’s test anxiety, which has been found to correlate with ER (Putwain et al., 2013), MA and math achievement (Caviola et al., 2022). Therefore, future studies could consider this factor as well.

4.5 Conclusions

Given a growing trend of “mathematization of society” (Jablonka & Gellert, 2007), the world requires more than ever, to equip students with the necessary mathematical knowledge and skills to effectively participate, as aware citizen, in this “mathematized world”. The present study highlights the intricate interplay of multiple factors in predicting math achievement. Specifically, the findings underline the role of ER as a significant individual difference variable that influences math performance through its impact on MA, which subsequently affects visuo-spatial WM resources. Recognizing the protective role of ER, on one hand, enables us to broaden our comprehension of students' diverse responses to math learning and, on the other hand, provides insights for developing more effective interventions to contrast negative feelings (Passolunghi et al., 2020).

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5. STUDY FOUR

Comparing Cognitive and Emotional-Motivational Interventions to Enhance Word Problem-Solving Skills in Primary School: A Randomized Controlled Study[4]

Abstract

Despite increasing evidence of the impact of emotional-motivational (EM) factors on word problem-solving performance, most research has primarily examined the effectiveness of intensive cognitive-based interventions to enhance this skill. This study aimed to compare the effects of two novel, non-intensive word problem-solving interventions on typically developing third- to fifth-graders. The first targets the cognitive components (CC) of problem-solving (e.g., text comprehension, problem representation, planning, and metacognition) and the second focuses on emotion-motivational (EM) factors, specifically math anxiety. A total of 442 children (M_{age}= 8.71 years, *SD* = .84) were randomly assigned to one of three conditions: CC intervention, EM intervention, or a business-as-usual control group. Each intervention consisted of eight 50-minute sessions. Pre- and post-intervention assessments measured word problem-solving ability, problem representation skills, and math anxiety. Multilevel modeling, accounting for classroom-level effects, showed that the CC intervention led to significant improvements in word problem-solving performance, problem representation skills, and reductions in math anxiety compared to the control group. The EM intervention effectively reduced math anxiety but did not significantly enhance word problem-solving performance or problem representation skills. Additionally, there was no significant difference between the CC and EM interventions in terms of reducing math anxiety. These findings highlight the greater efficacy of CC interventions to improve word problem-solving abilities and emphasize the need to integrate structured cognitive strategies into classroom instruction to promote problem-solving skills.

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5.1 Introduction

Arithmetic word problems (AWPs), defined as arithmetic problems presented in a verbal format (Verschaffel et al., 2020), constitute a significant component of mathematics curricula in primary schools worldwide (Daroczy et al., 2015; Jaffe & Bolger, 2023). AWPs are essential for helping students apply mathematical knowledge to real-world situations (Boonen et al., 2016), fostering creative and critical thinking skills, and enhancing overall problem-solving abilities (Boonen et al., 2013; Depaepe et al., 2010; Hickendorff, 2013; Verschaffel et al., 2020). Notably, children's ability to solve AWPs is a strong predictor of success in mathematics, as well as their employment prospects, career opportunities, and potential earnings in adulthood (Batty et al., 2010; Every Child a Chance Trust, 2009; Murnane et al., 2001; Ritchie & Bates, 2013; Wei et al., 2013). Yet, AWPs are a stumbling block for many students, even when their calculation skills are adequate (Daroczy et al., 2015). For instance, in Italy – where the present study took place – data from the national assessment for mathematics (INVALSI, 2023) show that only 54% of fifth graders can solve AWPs like the following: "The Asinelli Tower in Bologna is 97.20 meters tall and has an internal staircase with 498 steps. Lavinia has already climbed 1/3 of the staircase. How many steps has Lavinia climbed?".

Given the importance of AWP-solving skills and the substantial difficulties students encounter, it is crucial to develop effective instructional interventions (Kong et al., 2021). Despite the increase in intervention research aimed at improving AWP-solving abilities in primary school children, most studies have focused on intensive cognitive-based interventions for children with or at risk for mathematics difficulties (e.g., Fuchs et al., 2019, 2020, 2021; Kong & Swanson, 2019; Powell et al., 2021). Gaps remain in understanding the effects of less intensive interventions on typically developing students and in comparing the effects of cognitive interventions and emotional-motivational (EM) interventions. Although neglected, the EM aspect is relevant in AWP-solving (and math learning in general), significantly influencing engagement and perseverance (Pekrun, 2006; Dweck, 2006), cognitive strategies (Ramirez et al., 2016), and problem-solving performance (Doz et al., 2023, 2024; Lai et al., 2015; Passolunghi et al., 2019).

The present randomized controlled study aimed to advance the field by evaluating and comparing the effects of two novel non-intensive AWP-solving interventions on typically developing third- to fifth-grade children: one intervention focused on the cognitive factors and the other on EM factors. By comparing these interventions, we aimed to gain insights into strategies schools can use to reduce the AWP-solving achievement gap in primary school and to deepen our understanding of cognitive and EM factors as causal agents in AWP-solving.

In the following sections of this introduction, we provide a framework for understanding AWP-solving as a multifaceted process involving several cognitive components. The second section discusses the primary existing cognitive-based interventions designed to address the cognitive demands of AWP-solving. We then review theories and evidence on the influence of EM factors on AWP-solving, focusing on math anxiety, a key factor in math learning. Lastly, we review the primary EM interventions and highlight the gap in the literature, which has largely neglected EM factors in AWP-solving trainings, particularly in primary school children.

5.1.1 Cognitive Components of AWP-Solving

Solving AWPs is a complex and multifaceted process that involves more than just performing arithmetic calculations; it requires a thorough understanding of the problem's situation and selecting the correct mathematical operations (Lein et al., 2020; Lin, 2021). According to the theoretical framework by Mayer and colleagues (Mayer & Hegarty, 1996; Mayer et al., 1984), the AWP-solving process involves four key cognitive components (CCs): translation, integration, planning, and execution. The translation component (hereafter reading comprehension) involves an initial reading of the problem and translating each statement of the text into a propositional mental representation, which depend heavily on language comprehension abilities (Fuchs et al., 2019; Jaffe & Bolger, 2023; Peng et al., 2020). During the integration phase, the solver constructs a coherent mental model of the problem, known as the *problem representation* or *problem model*. This mental model represents the relationships between variables and clarifies the underlying semantic structure of the problem (Riley & Greeno, 1988; Riley et al., 1983). Next, in the planning phase, the solver develops a strategic plan to reach a solution, integrating prior knowledge with the problem model to set subgoals and determine appropriate arithmetic operations (Boonen et al., 2016; Hegarty et al., 1995; Kintsch & Greeno, 1985). An accurate problem representation is essential for effective planning; if the representation is incomplete or inaccurate, the solver is likely to encounter difficulties in devising a suitable solution strategy. Finally, in the execution phase, the solver performs the necessary arithmetic calculations as outlined in their plan.

In addition to these four cognitive components, Mayer's model recognizes the significance of a metacognitive component (Mayer, 1998). Metacognition, defined as one's awareness and regulation of their cognitive processes (Flavell, 1979), enables problem solvers to monitor their solving approach, adjust strategies if necessary, and ensure that the final solution is consistent with the problem requirements. Several studies have demonstrated that metacognitive skills are central in AWP-solving performance (Lucangeli et al., 1998; see also Jacobse & Harskamp, 2012).

Research consistently shows that difficulties in AWP-solving are often rooted in the initial CCs of problem-solving rather than in the execution of calculations (Hegarty et al., 1995; Kintsch & Greeno, 1985; Leiss et al., 2019; Mayer & Hegarty, 1996; Passolunghi et al., 2022; Wong & Yip, 2023; Yip et al., 2020). This is further supported by studies indicating that interventions specifically aimed at enhancing arithmetic skills tend to produce substantial improvements in calculation abilities, but yield smaller or no improvements in AWP-solving performance (Fuchs et al., 2013, 2021). In summary, while calculation skills are necessary for solving AWPs, they are often not the primary source of difficulty. Instead, challenges more commonly arise from constructing accurate problem representations—process that depends on reading comprehension as well as the capacity of working memory (Passolunghi et al., 2022).

5.1.2 Cognitive Components Interventions

In line with the significance of problem representation, meta-analytic findings indicate that interventions designed to improve children’s ability to accurately represent problems are among the most effective strategies (see meta-analyses by Kong et al., 2021; Lein et al., 2020; Myers et al., 2022; Zheng et al., 2013). One such cognitive strategy is the model method, also known as the bar diagram method (de Koning et al., 2022; Morin et al., 2017; Ng & Lee, 2009; Sharp & Dennis, 2017; Swanson, Lussier et al., 2013; van Garden, 2007). This instructional approach encourages students to visuo-spatially represent the situational model of AWPs using bar diagrams, thus supporting in particular the integration of information into a global situational model. By constructing a clear visuo-spatial representation, students can understand the relationships between different elements of the problem, and consequently more easily grasp the problem’s mathematical structure (Ainsworth & Th Loizou, 2003; Ayabe et al., 2022; de Koning et al., 2022). This approach also supports students’ working memory, since children are instructed to draw the information instead of manipulating them in memory (Fuchs et al., 2021; Swanson et al., 2013). Prior research has demonstrated the effectiveness of the model method in supporting AWP-solving across various types of problems (Ho & Lowrie, 2014; Ng & Lee, 2005, 2009) and for different types of learners, including those with learning disabilities (Morin et al., 2017; Sharp & Dennis, 2017; Swanson et al., 2013) and typically developing children (de Koning et al., 2022).

In addition to interventions focused on problem representation, research indicates that those aimed at enhancing reading comprehension, planning, and metacognition can also significantly improve AWP-solving performance. For instance, regarding reading comprehension interventions often include structured strategies, such as "attack strategies", which guide students through understanding the problem's meaning. These strategies emphasize careful reading, identifying key elements, and filtering out irrelevant information (Fuchs et al., 2014; Powell et al., 2019). This focus on understanding the narrative structure of the problem, rather than simply scanning for numbers, is crucial for understanding the problem’s situation and constructing an accurate mental representation (Powell & Fuchs, 2018). Additionally, interventions that teach the meanings and applications of problem-specific vocabulary—such as superordinate categories and implicit quantity verbs—have been shown to be effective. Fuchs et al. (2021) found that a word problem-solving intervention with embedded language comprehension instruction yielded to stronger improvements compared to a word problem-solving intervention without embedded language comprehension.

Interventions targeting the planning component have also proven effective in improving AWP-solving abilities. For instance, Schukajlow and Krug (2013) found that interventions emphasizing multiple solutions to AWPs encourage students to engage more frequently in strategic planning and metacognitive monitoring throughout their problem-solving process. This approach enables students to better organize their thoughts, evaluate different strategies, and ensure the accuracy of their solutions. Furthermore, generating multiple solutions fosters the use of working memory, as students must keep track of various approaches and evaluate their effectiveness.

Lastly, metacognitive interventions have also demonstrated efficacy (e.g., Lee et al., 2014; Montague, 2008). For instance, Pennequin et al. (2010) demonstrated that metacognitive training improved metacognitive knowledge, metacognitive skills, as well as problem-solving performance among third graders, with particularly strong benefits for lower-achieving students, who typically show impairments in metacognitive abilities (Garrett et al., 2006).

In summary, research underscores the importance of supporting the CCs of reading comprehension, problem representation, strategic planning, and metacognition in improving AWP-solving performance, as supported by Mayer’s theoretical model (Mayer & Hegarty, 1996). Since each component contributes uniquely to AWP-solving (Lucangeli et al., 1998), it would be important to support all CCs. However, to the best of our knowledge, no study has attempted to verify the effects of an intervention that supports all the main CCs involved in AWP-solving. Therefore, this study aims to develop and evaluate an integrated intervention that combines instruction on reading comprehension, the model method for problem representation, strategic planning, and metacognitive skills, addressing all key CCs involved in AWP-solving.

5.1.3 Emotional-Motivational Factors in AWP-Solving

Student achievement in AWP-solving can be significantly influenced by EM aspects (Eccles & Wigfield, 2024; Efklides, 2011), particularly math anxiety (Barroso et al., 2021). Math anxiety is defined as a specific emotional response characterized by feelings of tension and anxiety that interfere with tasks involving numbers (Richardson & Suinn, 1972). It can be conceptualized as both a trait and a state (Cipora et al., 2022): trait math anxiety refers to a relatively stable disposition or tendency to experience anxiety when engaging with mathematical tasks, while state math anxiety refers to the temporary, situation-specific feelings of anxiety that arise during particular mathematical activities, and can be influenced by various situational factors, such as the immediate environment or pressure during a math task. In the present study, we focused on trait math anxiety, as our goal was to explore whether interventions could effectively alleviate this more stable characteristic.

Research has extensively demonstrated that trait math anxiety has a moderately negative relationship with mathematical performance (ranging from $r = -.34$ to $r = -.32$) and starts to take root in childhood (Caviola et al., 2022; Demedts et al., 2022; Szczygieł et al., 2024; Zhang et al., 2019). The negative effect of math anxiety emerges across various mathematical tasks, including simpler arithmetic and computation tasks (Cuder et al., 2023; Harari et al., 2013; Hill et al., 2016; Lee & Cho, 2018), as well as more complex AWP-solving tasks (Doz et al., 2023, 2024; Lai et al., 2015; Passolunghi et al., 2019).

In particular, math anxiety is thought to impair performance by initially disrupting the pre-processing of information, leading to diminished engagement, reduced motivation, and an increased tendency to avoid math tasks (Chinn, 2009; Jenifer et al., 2022). Additionally, math anxiety affects information processing during tasks by interfering with working memory, which is critical for solving math problems (Ashcraft & Kirk, 2001; Doz et al., 2024; Eysenck & Calvo, 1992; Pellizzoni et al., 2022), and by influencing metacognitive experiences, self-regulation, cognitive resource allocation, and reducing persistence (Doz et al., 2023; Meyer & Turner, 2006; Verkijika &

De Wet, 2015). Recent longitudinal studies found that the relationship between math anxiety and math achievement is bidirectional (Aldrup et al., 2020; Du et al., 2021; Gunderson et al., 2018). Pekrun et al. (2017) tested fifth to ninth graders and found that negative emotions predicted lower math achievement, which, in turn, led to more negative math emotions, creating a vicious cycle. Similar results were observed in younger children just beginning formal schooling, specifically in first and second graders (Szczygieł et al., 2024). Consequently, EM interventions aimed at reducing math anxiety could be beneficial in breaking this negative cycle and promoting better math achievements (Balt et al., 2022; Passolunghi et al., 2020).

5.1.4 Emotional-Motivational Interventions

In general, EM interventions aimed at targeting math anxiety fall into two main approach categories: mathematical intervention approach and cognitive-behavioral intervention approach (Balt et al., 2022). While mathematical intervention approach aims to reduce math anxiety indirectly by strengthening math skills (this is, cognitive interventions), cognitive-behavioral intervention approach directly targets anxiety-related cognitions (e.g., negative thoughts and rumination about one's abilities or fear of failure) with techniques such as reappraisal, growth mindset training, and coping strategies.

Reappraisal involves changing the way a situation is interpreted in order to reduce its emotional impact (Hofmann et al., 2009). This technique is considered one of the most effective methods for decreasing negative emotion and physiological arousal in response to distressing emotional stimuli (Chodkiewicz & Boyle, 2016; Hembree, 1990). Growth mindset is defined as the belief that intelligence and abilities can be developed through effort and learning (Dweck, 2008; Yeager & Dweck, 2012). Studies show that the growth mindset is linked to lower math anxiety through attribution failure (Dong et al., 2023), where students with higher growth mindset attribute failure in mathematics to controllable characteristics (e.g., insufficient efforts) rather than math abilities. Intervention studies on adults suggest that fostering a growth mindset, along with a failure-as-enhancing attitude and flexible problem-solving strategies, can help alleviate math anxiety (Samuel & Warner, 2019; Samuel et al., 2022; Smith & Capuzzi, 2019; Young & Dyess, 2021). Lastly, coping strategies help manage or regulate worries and negative emotions that often guide negative appraisals (Ashcraft & Kirk, 2001; Ramirez et al., 2018). Strategies like breathing exercises, safe place visualization, and expressive writing have been shown to help students process and regulate anxiety in specific situations (Hines et al., 2016). For instance, Park et al. (2014) found that expressive writing before a math test, in which participants wrote openly regarding how they felt about an upcoming math test, improved performance in highly math-anxious adults.

Although cognitive-behavioral interventions focusing on reappraisal, growth mindset and coping strategies have been found effective in mitigating feelings of math anxiety, their effects on actual math performance are mixed. Some studies with developmental samples suggest that these interventions can improve both math anxiety and math achievement (e.g., Kim et al., 2017; Ruff & Boes, 2014; Sheffield & Hunt, 2006; Singh, 2016). However, other studies indicate that while these interventions reduce math anxiety, they do not lead to improvements in math skills (e.g., Passolunghi et al., 2020; Samuel et al., 2022). For instance, Passolunghi et al. (2020) compared a mathematical and a cognitive-behavioral intervention approach in fourth graders and found that while both interventions reduced math anxiety, only the mathematical intervention improved children’s math skills.

In summary, literature has demonstrated the significant negative impact of math anxiety on AWP-solving performance and suggests that EM interventions incorporating reappraisal techniques, growth mindset principles, and coping strategy are effective in reducing math anxiety and, in some cases, improving math performance. However, to date no studies have specifically examined the impact of these interventions on AWP-solving in primary school students.

5.1.5 Present Study

In the present study, we designed and evaluated the efficacy of two novel non-intensive interventions aimed at promoting AWP-solving abilities in typically developing primary school students. The first intervention focused on the main CCs of AWP-solving (i.e., reading comprehension, problem representation, planning, and metacognition; Mayer, Larkin, & Kadane, 1984; Mayer & Hegarty, 1996). The second intervention targeted the EM aspects linked to AWP-solving, specifically addressing math anxiety (reappraisal, growth mindset, and coping strategies; Chodkiewicz & Boyle, 2016; Passolunghi et al., 2020; Samuel et al., 2022). These interventions were compared with one another and with a business-as-usual (BAU) control group to account for maturation, historical effects, and typical schooling influences.

We were interested in assessing and comparing the effects of these interventions on improving AWP-solving ability, as well as problem representation skill, and math anxiety. Regarding AWP-solving ability, we hypothesized that the CC intervention would outperform the BAU control group (Kong et al., 2021; Lein et al., 2020), whereas no specific hypothesis was made for the EM intervention given the mixed results in literature (Balt et al., 2022; Sammallahti et al., 2023). Additionally, we expected the CC intervention to outperform both the BAU control and EM conditions in problem representation (Ng & Lee, 2009), while the CC intervention and EM interventions were hypothesized to be more effective in reducing math anxiety compared to the BAU control group (Passolunghi et al., 2020; Sammallahti et al., 2023).

The study extends the literature on AWP-solving interventions in several directions. Firstly, it compares the effects of cognitive and EM approaches. Extensive research has shown that both cognitive and EM factors predict problem-solving performance (Lai et al., 2015; Passolunghi et al., 2019). Despite these findings, existing AWP-solving interventions focus only on CCs. Our study addresses this gap by experimentally comparing the effects of CC and EM interventions on AWP-solving outcome, thereby enhancing our understanding of their distinct impacts on performance. Exploring the effects of an EM intervention on AWP-solving would also provide strong evidence supporting the hypothesis that negative attitudes, such as math anxiety, are causal agents in AWP-solving difficulties.

Secondly, this study specifically targets typically developing children, a population often overlooked in favor of those with math learning disabilities (MLD) or those at risk for MLD. While it is crucial to explore interventions for children with MLD, it is equally important to identify effective strategies for typically developing children, who also exhibit a significant percentage of below-average performance in AWP-solving tasks (INVALSI, 2023).

Lastly, these interventions are designed to be non-intensive, collective, and easily implemented in classroom settings, in contrast with the more common intensive, small-group formats used in previous studies (e.g., Fuchs et al., 2021; Jitendra et al., 2007; Powell et al., 2023). As highlighted by the meta-analysis by Kong et al. (2021), there is a need to develop and implement instructions for all students (i.e., Tier I instruction of the three-tier model for instructional support and services[5]) before utilizing additional resources for more intensive and individualized programs. This study aims to determine whether short and less intensive interventions can also be effective, providing valuable insights for practitioners and educators looking to integrate such interventions into regular school activities.

5.2 Method

5.2.1 Participants

We recruited a total of 490 third, fourth and fifth graders from 25 classrooms in 7 state primary schools in northeastern Italy. At the beginning of the study, 40 children were excluded for the following reasons: limited Italian proficiency (*n* = 13), Specific Learning Disability diagnosis (*n* = 10), disability and receiving other services (*n* = 17). The remaining 450 students completed pretesting across a two-week span and then were randomly assigned, blocking by classroom, to one of three conditions: CC intervention, EM intervention, and a BAU control group. From the start of intervention through posttesting, eight children were absent for more than two of the eight training

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[5] The three-tier model provides a structured approach to educational support through three levels of intervention: Tier I involves universal, high-quality instruction for all students; Tier II offers targeted, small-group interventions for those who need additional help; and Tier III provides intensive, individualized support for students with significant needs.

sessions and were subsequently excluded from the analysis (1.8% overall attrition rate). Therefore, the final sample consisted of 442 children (M_{age}= 8.71 years, *SD* = .84, age range: 7-11 years, 229 females), resulting in the following breakdown: 161 children in the CC condition (M_{age}= 8.75 years, *SD* = .85, 87 females), 123 children in the EM condition (M_{age}= 8.60 years, *SD* = .73, 63 females), and 158 in the BAU condition (M_{age}= 8.75 years, *SD* = .90, 79 females). All participants were Caucasian children of middle-class socioeconomic status, based on school records.

The study received approval by the ethical committee of the University of Trieste and was conducted in compliance with the Declaration of Helsinki, the ethical guidelines of the Italian Association of Psychology and the ethical code of the Italian Register of Professional Psychologists. Written informed parental consent was obtained before assessing the students and all children participated voluntarily.

5.2.2 Pretest and Posttest Measures

At both the pretest and the posttest, three trained graduate students, who were blind to the participants' intervention assignments, administered measures evaluating students' AWP-solving skills, problem representation abilities, and math anxiety.

Arithmetic Word Problem-Solving

The *Word problem test* derived from the Italian standardized battery AC-MT 6-11 (Cornoldi et al., 2020) consists of five AWPs, similar to those typically found in Italian mathematics textbooks and required by the national math curriculum (Cornoldi et al., 2020). These problems require the use of all four arithmetic operations: addition, subtraction, multiplication, and division. Each grade level (third, fourth, and fifth) has its own version of the test, with age-appropriate complexity and knowledge. Among the five problems, one requires a single arithmetic operation to solve, while the other four problems require two operations. The two-step problems combine an addition/subtraction operation with either another addition/subtraction operation or a multiplication/division one. To evaluate the students' ability to understand the problem's situation, we included an additional problem that could not be solved due to missing numerical data (adapted by Baruk, 1985). An example of this problem for fourth graders is "The train to Rome stops at Venice: 3 people get off and 5 get on. How many seats are now available on the train?". Thus, the final version of the measure included six problems: five standard problems and one non-standard. Participants were instructed to carefully read each problem and encouraged to use their preferred solving strategy. Each problem was scored as follows: one point was awarded for each correct operation (i.e., the child identified the correct arithmetic operation and performed correctly the calculation), 0.5 points were awarded when children identified the correct operation but a calculation mistake was made, and 0 points were given when children identified the incorrect operation. The final score ranged from 0 to 10.

Word Problem Representation

At pretest and posttest, the Italian adaptation of *Word problem reasoning task* (Yip et al., 2020) was used to assess the children's ability to represent and identify different types of AWPs. The task comprises eight simple addition or subtraction problems divided into three problem types, namely combine, change, and compare, with the change type further subdivided into change-increase and change-decrease subtypes. Each problem type/subtype is represented by two problems, with varying positions of the unknown variable. Four problems have the unknown item in the third position (e.g., "Mat had 8 candies, and he ate 2 candies. How many candies does he have now?"), while the other four have the unknown item in the first or second position (e.g., "Sarah has some candies. She receives 2 more candies, and now she has 5 candies. How many candies did she have in the beginning?"). Next to the problems, there are four pictures abstractly illustrating the mathematical structure of each problem type (for an example, see the original measure by Yip et al., 2020). Participants were asked to identify which picture best represented the given AWP and match it with the picture. While the AWPs involve discrete quantities (i.e., candies), the pictures involve continuous quantities (i.e., water). This serves to shift the focus away from superficial details, encouraging the participants to seek structural similarities between the problems and the pictures. Each correct response was awarded one point. The total score was the sum of the correct responses, ranging from 0 to 8. The measure showed good reliability (Cronbach’s α = .68).

Math Anxiety

At pretest and posttest, the *Abbreviated Math Anxiety Scale* (AMAS; Hopko et al., 2003; Italian adaptation for primary school children by Caviola, Primi, et al., 2017) was used to evaluate math anxiety levels. AMAS is a brief questionnaire that comprises nine statements describing situations involving mathematical activities (i.e., math learning and math testing). Children have to determine how anxious they would feel in each depicted situation, using a 5-point Likert scale (1 = *a little anxious*; 5 = *extremely anxious*). The total score was the sum of the scores on each item, ranging from 9 to 45, with higher scores indicating greater levels of math anxiety. In the present sample, a good reliability of the scale was observed (Cronbach’s α = .79).

5.2.3 Interventions

Commonalities across conditions

The structure of the interventions is presented in Figure 5.1. Both CC and EM interventions included one 50-minute session per week, administered over 8 weeks. The sessions were conducted collectively in the classroom by trained researchers, with classroom teachers present to assist with discipline if required. To foster pupil interest, both interventions incorporated an ocean theme (e.g., starfish reward stickers, underwater animal manipulatives).

Each session of CC and EM intervention conditions followed a structured format composed of five activities, which have been found effective in the word problem intervention literature (Kong et al., 2021). The first activity was a warm-up review lasting 5-10 minutes, during which students reviewed the strategies taught during the previous lesson and completed an example independently, receiving immediate feedback. This was followed by a direct instruction for the whole class that lasted 10 minutes, during which the researcher introduced a cognitive or emotional-motivational strategy with examples, using visuals, manipulatives, and role-playing. Third, a metacognition-building activity was presented that lasted 5 minutes, during which students reflected on the usefulness of the strategy. Fourth, individual or group practice lasting 20 minutes were presented, during which students worked independently or in small groups to apply the newly learned strategy. Finally, a feedback and motivational activity that lasted 5 minutes was given, which allowed for reflection and self-regulation. After the feedback, each student colored a progress poster to visually track their progress and received a sticker as a reward. Incorporating motivators and reinforcers was an essential part of interventions, as they help students regulate their attention and behavior and encourage hard work (Fuchs et al., 2008).

Cognitive Components intervention

The CC intervention focused on promoting the cognitive components of AWP-solving, as outlined by the Mayer's model (Mayer & Hegarty, 1996; Mayer et al., 1984), and comprised three thematic modules: text comprehension (sessions 1–3), problem representation (sessions 4–6), and planning (sessions 7–8). Metacognition was integrated throughout all 8 sessions.

The text comprehension module aimed to promote the understanding of the problem's text. Children were instructed to avoid a "keyword strategy" (Powell & Fuchs, 2018), a superficial strategy based on the identification of a keyword that is typically associated to a math operation (e.g., in all = addition). They were taught an attack strategy to guide a deep comprehension of the text, which included three steps, which were practiced in the three sessions. In Session 1 children were instructed to read the problem thoroughly, underline and reflect on the question, as well as identify relevant information. In Session 2 children learned to identify and cross out irrelevant information. Session 3 involved identifying any missing information. Moreover, children were presented with activities to develop better language comprehension (Fuchs et al., 2021): children were taught math vocabulary (e.g., increased by, decreased by) and implicit language, such as superordinate categories (e.g., students = girls and boys), hidden numerical information (e.g., week = 7 days), and implicit quantity change verbs (e.g., eating = decreasing quantity of food).

The problem representation module aimed to promote the integration of information into a coherent mental model through the visual-schematic strategy of the model method (see Ng & Lee, 2009). Children were taught that solving word problems with the model method involves essentially three phases (de Koning et al., 2022). In the first phase the solver reads the given word problem with the intention to identify the known as well as the unknown information (as practiced in the text comprehension module). In the second phase, the learner represents the identified text information graphically using the bar diagram. The solver draws a set of rectangles where each rectangle represents the quantity of a variable. The second phase is complete when all the information is combined into a series of rectangles. In the third and last phase, the visual representation of the bar diagram drawn in the previous phase helps the learner to decide which operation needs to be performed and to formulate the mathematical equation required to solve the problem. Children were taught to use bar diagrams for both additive and multiplicative problems. Specifically, session 4 focused on additive problems, session 5 on multiplicative problems, and session 6 covered both additive and multiplicative problems.

Lastly, the planning module was designed to enhance the students' ability to plan and organize the problem-solving steps for both simple multi-step problems (session 7) and complex multiple-step problems (session 8), thereby fostering strategic thinking and organizational skills. Children were asked to determine the number of operations needed to solve the problem, break down the problem into manageable steps, organize the sequence in which these steps should be executed, and plan the appropriate mathematical operations for each step.

Emotional-Motivational Intervention

The EM intervention was specifically designed to enhance AWP-solving by targeting math anxiety. It drew from previous intervention studies employing a cognitive-behavioral approach that integrated cognitive reappraisal, growth mindset principles, coping strategies and metacognition (Chodkiewicz & Boyle, 2016; Passolunghi et al., 2020; Samuel & Warner, 2019; Samuel et al., 2022). Like the CC intervention, the EM intervention was organized into three thematic modules: reappraisal (sessions 1-3), growth mindset (sessions 4-6), and coping strategies (sessions 7-8). Metacognition was integrated throughout all 8 sessions.

The reappraisal module had the goal to teach children a more adaptive thinking style in relation to mathematics. Session 1 focused on recognizing different emotions, including anxiety, and comprehending the link between thoughts, emotions, and actions (Chodkiewicz & Boyle, 2016). In Session 2 children were taught to identify helpful and unhelpful thinking patterns related to mathematics and AWP-solving, and practice recognizing one's own thinking patterns (Chodkiewicz & Boyle, 2016). In Session 3, children learned to transform negative thoughts into more helpful ones using cognitive-behavioral therapy techniques for children (Di Pietro, 2014; Ellis & Bernard, 2006).

The growth mindset module aimed to encourage children to view mathematical knowledge as something that can be developed through effort, rather than as an innate talent. In Session 4, children were introduced to the idea that anyone can learn math with the necessary effort and perseverance (Dweck, 2000). Activities involved solving increasingly challenging math problems and engaging in metacognitive reflection, where students wrote about how their effort helped them overcome challenges. Session 5 focused on reframing failure as an opportunity for growth (Ramirez et al., 2018). They were taught strategies to effectively learn from their mistakes (e.g., highlighting mistakes with their favorite color) and participated in exercises where they intentionally made mistakes and learned from the process. Session 6 promoted flexibility in math learning. Activities included solving the same problem using different solving strategies and discussing the advantages and disadvantages of each approach.

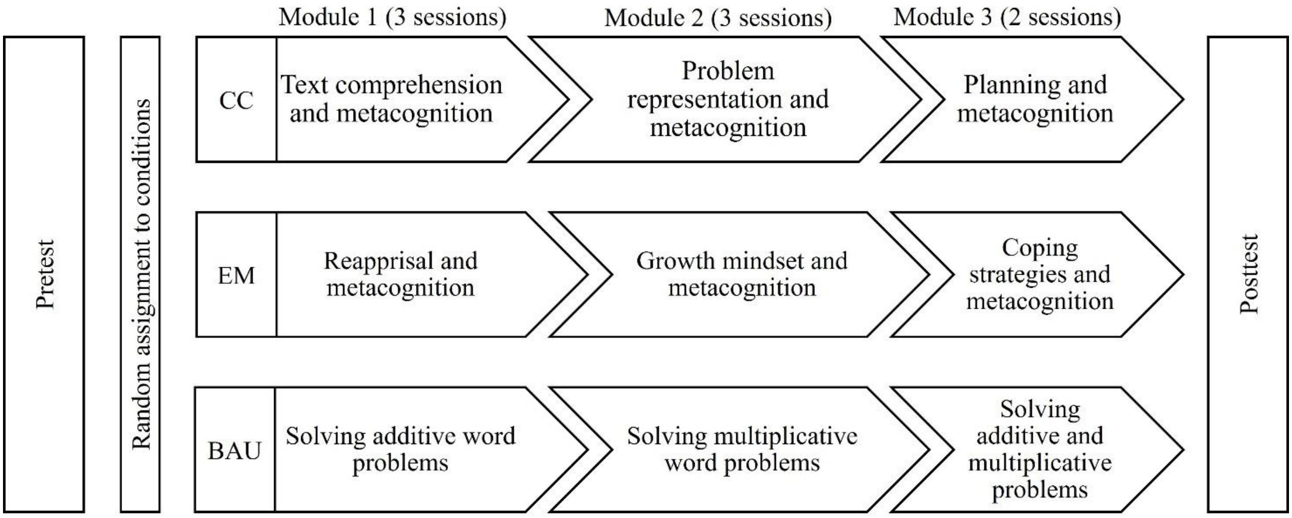
During the coping strategies module, children were taught strategies to manage feelings of anxiety and worries during specific situations (e.g., homework, tests, exams). In accordance with literature (Park et al., 2014; Passolunghi et al., 2020), these techniques included: a) breathing exercises, b) safe place visualization, and c) expressive writing. In Session 7 all the strategies were presented and explained, and in Session 8 participants engaged in various games and playful activities to practice these techniques. Metacognition was also integrated to help children identify their best approach to manage anxiety.

BAU control group

Students in the BAU control group received standard mathematics instruction provided by their regular classroom teachers, who relied on national textbooks as the primary curriculum source. The BAU instruction was structured similarly to the CC and EM intervention conditions and was divided into three thematic modules: solving additive word problems (sessions 1–3), solving multiplicative word problems (sessions 4–6), and solving both additive and multiplicative problems involving more complex calculations (sessions 7–8). The BAU approach focused on key-word heuristics, such as instructing students to read the problem text, underline the question, identify and circle keywords (e.g., “in total” or “altogether” for addition, “difference” or “less” for subtraction), rewrite the given information, and then perform the calculation to solve the problem. Importantly, this instructional method did not emphasize deeper problem representation skills.

Figure 5.1

Study Design: Representation of the Interventions' Structure



Note. CC = Cognitive Component intervention; EM = Emotional-Motivational intervention; BAU = business-as-usual control

5.2.4 Data Analysis

Statistical analyses were performed with IBM SPSS software. Since the study's data structure is nested, we employed a multilevel approach (Field, 2004). In particular, the data involved three levels of nesting: 442 students nested within 25 classrooms nested in 7 schools. Thus, to explore the effects of nesting, we fit three-level multilevel models (Raudenbush & Bryk, 2002), which indicated that the random effects at the school level were not supported by the data due to a lack of variability at that level. So, we removed the random effects at the school level and estimated a more parsimonious two-level model using a full-information robust maximum likelihood estimation.

The aim of the study was to evaluate the main effect of the intervention condition on word problem-solving outcome controlling for pretest word problem-solving ability; the main effect of intervention condition on problem representation ability, controlling for pretest problem representation ability; and the main effect of the intervention condition on math anxiety, controlling for pretest math anxiety. These objectives were examined using the multilevel models presented in Equations 1–3.

(1)

$$postWPS_{ij} = \beta_{0j} + \beta_{1j}D1_{ij} + \beta_{2j}D2_{ij} + \beta_{3j}preWPS_{ij} + e_{ij}$$

$$\beta_{0j} = \gamma_{00} + \mu_{0j};\ \beta_{1j} = \gamma_{01};\ \beta_{2j} = \gamma_{02};\ \beta_{3j} = \gamma_{03}$$

(2)

$$postPR_{ij} = \beta_{0j} + \beta_{1j}D1_{ij} + \beta_{2j}D2_{ij} + \beta_{3j}prePR_{ij} + e_{ij}$$

$$\beta_{0j} = \gamma_{00} + \mu_{0j};\ \beta_{1j} = \gamma_{01};\ \beta_{2j} = \gamma_{02};\ \beta_{3j} = \gamma_{03}$$

(3)

$$postMA_{ij} = \beta_{0j} + \beta_{1j}D1_{ij} + \beta_{2j}D2_{ij} + \beta_{3j}preMA_{ij} + e_{ij}$$

$$\beta_{0j} = \gamma_{00} + \mu_{0j};\ \beta_{1j} = \gamma_{01};\ \beta_{2j} = \gamma_{02};\ \beta_{3j} = \gamma_{03}$$

where $e_{ij} \sim N(0, \sigma^2);\ \mu_{0j} \sim N\left(0, \tau_{00}^{(2)}\right)$.

In these equations, *i* indexes student, whereas *j* indexes classroom. β_{0j} represents the classroom-specific intercept (mean outcome for each classroom), and γ_{00} represents the overall mean intercept (grand mean). e_{ij} is a student-level residual with variance σ^2, and μ_{0j} is classroom-level deviation from the average intercept γ_{00} with variance of $\tau_{00}^{(2)}$. $postWPS_{ij}$ is posttest word problem-solving outcome, $postPR_{ij}$ is posttest problem representation outcome, and $postMA_{ij}$ is posttest math anxiety outcome. $preWPS_{ij}$ is pretest word problem-solving ability, $prePR_{ij}$ is pretest problem representation ability, and $preMA_{ij}$ is pretest math anxiety. $D1_{ij}$ and $D2_{ij}$ are dummy variables representing, respectively, CC intervention versus BAU control, and EM intervention versus BAU control. We tested the difference between CC and EM intervention by testing $(\gamma_{02} - \gamma_{01}) = 0$.

To assess the effect sizes between conditions, we computed Hedges' *g*, which is the mean difference divided by the pooled weighted standard deviation (Hedges, 1982). We classified the effect sizes as small (0.20), medium (0.50), and large (0.80) based on Cohen's criteria (1988).

5.3 Results

Table 5.1 presents means and standard deviations at pretest and posttest for all three conditions (CC, EM and BAU). For the three outcome variables (word problem-solving, representation ability and math anxiety), intraclass correlations at the classroom level were .097, .203, and .104, respectively. Results of the main effects of multilevel models as well as Hedges' *g* effect sizes between conditions are presented in Table 5.2.

Table 5.1

Means and Standard Deviations by Study Condition

Variable	**CC** ***M (SD)***	**EM** ***M (SD)***	**BAU** ***M (SD)***
Word problem-solving			
Pretest	3.21 (2.01)	3.60 (1.69)	3.07 (2.13)
Posttest	5.49 (2.57)	4.49 (2.52)	4.36 (2.54)
Representation ability			
Pretest	5.44 (1.73)	5.59 (1.63)	4.41 (2.25)
Posttest	6.11 (1.45)	5.25 (1.41)	4.94 (1.78)
Math anxiety			
Pretest	21.76 (6.24)	22.29 (6.93)	24.31 (6.88)
Posttest	19.75 (6.26)	20.80 (6.92)	24.32 (7.32)

Note. CC = Cognitive Components intervention; EM = Emotional-Motivational intervention; BAU = business-as-usual control group.

In evaluating the main effect of the intervention on word problem-solving while controlling for pretest word problem-solving ability, the CC intervention demonstrated a significantly stronger effect compared to both the BAU control and EM intervention conditions. Conversely, the EM intervention did not show a statistically significant difference from the BAU control condition. Regarding the main effects on problem representation ability, after controlling for pretest problem representation skills, the CC intervention again exhibited a stronger impact than both the BAU control and EM interventions, while the EM intervention's effect was not significantly different from that of the BAU control. Lastly, when assessing levels of math anxiety, controlling for pretest math anxiety levels, both the CC and EM conditions showed significant reductions compared to the BAU control group, with no significant difference between the two interventions themselves.

Table 5.2

Main Effects of Two-Level Multilevel Model

Model/Parameter	**Estimate**	**SE**	***p*-value**	**Hedge's *g* ES**
Word problem-solving				
Fixed effects				
Intercept	3.122	0.268	<.001	
CC vs. BAU	0.998	0.293	.007	.39
EM vs. BAU	-0.184	0.313	1.000	.07
CC vs. EM	1.182	0.313	.003	.46
Pretest word problem-solving	0.735	0.053	<.001	
Variance components				
Student-level residual	2.759	0.307		
Representation ability				
Fixed effects				
Intercept	4.709	0.298	<.001	
CC vs. BAU	0.876	0.297	.021	.50
EM vs. BAU	0.037	0.316	1.000	.02
CC vs. EM	0.839	0.310	.035	.52
Pretest representation ability	0.265	0.039	<.001	
Variance components				
Student-level residual	1.922	1.420		
Classroom-level intercept	0.514	0.114		
Math anxiety				
Fixed effects				
Intercept	7.330	1.116	<.001	
CC vs. BAU	-3.436	0.897	.002	.50

EM vs. BAU	-2.638	0.954	.032	.37
CC vs. EM	0.798	0.947	1.000	.12
Pretest math anxiety	0.563	0.042	<.001	
Variance components				
Student-level residual	30.481	2.230		
Classroom-level intercept	0.124	1.037		

Note. CC = Cognitive Components intervention; EM = Emotional-Motivational intervention; BAU = business-as-usual control group; ES = effect size.

Overall, the findings indicate that while the EM intervention was effective in lowering math anxiety, the CC intervention was the most beneficial, as it improved word problem-solving and problem representation abilities while concurrently reducing math anxiety levels.

5.4 Discussion

Most studies on AWP interventions among primary school children have focused on intensive cognitive-based approaches, often neglecting the effects of EM interventions (e.g., Fuchs et al., 2019, 2021; Kong & Swanson, 2019; Powell et al., 2021). The few studies that have evaluated both cognitive and EM interventions have aimed primarily at enhancing general math abilities rather than specifically targeting AWP-solving skills (e.g., Passolunghi et al., 2020). The purpose of the present study was to fill this gap by designing and assessing the efficacy of non-intensive CC and EM interventions in promoting AWP-solving abilities in typically developing primary school children. In addition to AWP-solving performance, we assessed the efficacy of these interventions in improving problem representation skills—the “heart” of AWP-solving (de Koning et al., 2022; Ng & Lee, 2009)—as well as in reducing math anxiety.

5.4.1 Effects of CC Intervention

The CC intervention, drawing upon the theoretical model of Mayer (Mayer & Hegarty, 1996;

Mayer et al., 1984), is designed to directly promote the CCs involved in AWP-solving (i.e., text comprehension, problem representation, planning, and metacognition). Our results demonstrated that the CC intervention compared to the BAU control group produced significant improvements in AWP-solving performance, problem representation ability, as well as contributed to a significant decrease in math anxiety in the form of far transfer.

With respect to AWP performance, the positive effect of the CC intervention supports previous studies indicating that providing students with cognitive strategies that promote the CCs of AWP-solving is beneficial (e.g., Fuchs et al., 2003, 2010; Morin et al., 2017; Ng & Lee, 2005, 2009; Sharp & Dennis, 2017; Swanson et al., 2013). Our study's results extend existing literature. Firstly, the findings indicate that the CC intervention is beneficial for typically developing children—a group that has often been overlooked in favor of those with or at risk for MLD (see the meta-analyses by Kong et al., 2021; Lein et al., 2020; Myers et al., 2022). These findings could inform improvements in teaching strategies at Tier I of the educational model (Kong et al., 2021) and contribute to the development of more effective textbooks (Vicente et al., 2022). Additionally, the study shows that even a non-intensive CC intervention can effectively and significantly enhance AWP-solving abilities in children. The observed effect size in the present study (g = 0.39) is considered small according to Cohen's criteria (1988) and is notably lower when compared to the effect sizes of more intensive cognitive-based interventions on typically developing children (e.g., Fuchs et al., 2003, 2010). For instance, Fuchs et al. (2003) examined the efficacy of a cognitive-based intervention conducted over 16 weeks and comprising 26 to 36 sessions and reported large effect sizes (between 2.61 and 1.81) in improving third grader AWP-solving performance on an ad hoc measure. The present CC intervention represents less than one-third of the duration of Fuchs' et al. (2003) intervention, yet it still offers some substantial improvements, indicating that non-intensive CC interventions may provide a practical and effective approach for schools. Lastly, it is important to note that improvement occurred on a norm-referenced AWP-solving test (Cornoldi et al., 2020). To date, many intervention studies have shown gains on researchers developed word problems measures, which in some cases were almost identical to those presented during interventions, and less so on standardized tests (see Lein et al., 2020; Powell, 2011). Thus, the performance improvement on standardized test materials observed in the present study underscores the robustness and practical applicability of the newly designed CC intervention.

Furthermore, the CC intervention specifically improved the core aspect of the AWP-solving process—the ability to integrate information into a coherent mental representation of the problem (de Koning et al., 2022). The focus on text comprehension and the use of the visuo-schematic strategy of the model method may help children more effectively organize and integrate problem information while also supporting working memory (Morin et al., 2017; Ng & Lee, 2009; van Garderen, 2007). By promoting a structured approach to understanding and representing the problem, the intervention likely facilitates the development of more accurate mental models, which then guides the planning phase. While other intervention studies have aimed to support problem representation, they have not explicitly confirmed whether the interventions effectively targeted this construct (e.g., Fuchs et al., 2010; Morin et al., 2017; Ng & Lee, 2005, 2009; Swanson et al., 2013). The results of the present study not only validate that our intervention successfully targeted the intended construct, but also underscore the importance of problem representation as a causal agent in AWP-solving (Yip et al., 2020).

Interestingly, the CC intervention led to improvements not only in AWP-solving and problem representation abilities, but also in reducing math anxiety. This finding aligns well with previous research (e.g., Balt et al., 2022; Passolunghi et al., 2020), which suggests that mathematical interventions can enhance both mathematical skills and positive emotions towards mathematics. The observed link between improved achievement and a decrease in negative emotions also supports the causal relationship between math performance and math anxiety, providing support for the deficit theory, which posits that poor early math performance is a risk factor for developing math anxiety (see Carey et al., 2016). It is possible that the improvements in AWP-solving gained during the CC intervention may contribute to an increase in student math self-efficacy, which in turn can lower feelings of math anxiety (Kyttälä & Björn, 2010; Passolunghi et al., 2020). Furthermore, the CC intervention involves repeated exposure to the object of anxiety in children, namely mathematical stimuli, which may lead to a process of systematic desensitization to these stimuli (Supekar et al., 2015). Through repeated practice, children can develop a sense of self-control over their fear-provoking stimuli, thereby reducing their math anxiety. This interpretation is supported by prior work indicating that systematic desensitization is among the most effective treatments for anxiety disorders (Van Etten & Taylor, 1998; Wolitzky-Taylor et al., 2008).

5.4.2 Effects of EM Intervention

The EM intervention has been designed to enhance AWP-solving performance by alleviating math anxiety through a combination of reappraisal techniques, growth mindset principles, and coping strategy training (Di Pietro, 2014; Dweck, 2000; Ellis & Bernard, 2006; Pizzie et al., 2020). Consistent with our hypothesis, the findings have revealed that the EM intervention was indeed effective in reducing children's math anxiety levels compared to the BAU control group. This result aligns with previous studies (e.g., Asanjarani & Zarebahramabadi, 2021; LaGue et al., 2019; Passolunghi et al., 2020; for a review see also Balt et al., 2022), which suggest that cognitive-behavioral interventions incorporating several reappraisal techniques, coping strategy training, and growth mindset principles can effectively reduce math anxiety even in young children.

Interestingly, when compared with the CC intervention, the results indicate that both interventions have been effective in alleviating math-related anxiety, with no significant difference in their effects. Consequently, and in agreement with the literature (Balt et al., 2022), the study recommends two distinct approaches to reducing negative emotions in mathematics: the first involves directly targeting beliefs related to mathematics and teaching strategies to cope with negative emotions, while the second is directed on promoting mathematical skills or knowledge, thereby reducing math anxiety indirectly (Ramirez et al., 2018).

Yet, the EM intervention did not produce any improvement in the ability to solve AWPs or the ability to represent the problem's situational structure compared to the BAU control group. This finding is in agreement with several previous studies demonstrating the difficulty of achieving a transfer effect from cognitive-behavioral interventions to math abilities, both in primary school children (e.g., Passolunghi et al., 2020), and older students (e.g., Samuel et al., 2022). The absence of a far transfer effect on math performance could depend on several factors. Firstly, it could be speculated that the posttest assessment was conducted too soon after the intervention and that the effect of reduced anxiety might not show up immediately in performance. Over time, as students feel less anxious, they may develop better study habits, persistence, or openness to seeking help, eventually improving performance. Including a follow-up measure after a longer period could potentially reveal the positive effects of reduced anxiety, which might gradually promote better performance and, in turn, interrupt the vicious cycle of math anxiety. Secondly, in the present study, the AWP-solving measure was untimed. There is some evidence suggesting that math anxiety may interact with timed or high-stakes conditions to cause a further performance decrement (see Caviola, Carey et al., 2017). If this is the case, the reduction in math anxiety might have a stronger positive impact on timed tasks compared to untimed tasks. Future EM intervention studies should therefore incorporate both types of math tasks and explore whether EM interventions offer greater benefits on performance in more stressful timed situations. Finally, it should be considered that AWPs are complex cognitive tasks, and reducing anxiety may free up cognitive resources previously consumed by stress (as suggested by the Processing Efficiency Theory; Eysenck & Calvo, 1992) and improve attentional control (Eysenck et al., 2007), but if students lack the necessary skills or knowledge this will not automatically lead to better performance. Consistent with this idea, the results showed that the EM intervention did not improve problem representation skills, that is to say, did not promote a cognitive ability specific to the AWP-solving process.

Overall, the study demonstrates a clear advantage of the CC intervention compared to the EM intervention in promoting AWP-solving abilities in primary school children.

5.4.3 Limitations and Future Directions

Although there are promising results, the findings of the present study should be interpreted in the context of some limitations. One notable limitation is the absence of a follow-up assessment, which prevents us to determine whether improvement in problem-solving skills and reduction in math anxiety are sustained over time. Additionally, the BAU control group in this study was passive, which allowed us to control for maturation, historical effects, and typical schooling influences. However, an active control condition, such as an alternative intervention, might provide a more rigorous comparison and help isolate the specific effects of the newly developed CC and EM interventions. In this respect, it would be helpful to compare our interventions with established ones, such as the model method or the schema-based instruction (see Fuchs et al., 2021), a common intervention aimed at supporting the problem representation. Future studies could also investigate the combined effects of an integrated CC and EM intervention (Leo & Muis, 2020) compared to CC-only or EM-only approaches. This would provide insights into whether a holistic approach offers more significant benefits in math performance and anxiety reduction. Finally, this study did not control for other important variables, such as reading comprehension and working memory, which are known to impact AWP-solving performance (Lin, 2021). Controlling for these variables in future research would help clarify the specific contributions of the intervention components.

5.5 Conclusions

This study aimed to advance research on AWP-solving interventions by comparing the effects of non-intensive CC and EM interventions on typically developing primary school children. Although there is increasing recognition of the influence of EM factors on math learning outcomes (Barroso et al., 2021; Caviola et al., 2022), our findings highlight the superior efficacy of the cognitive-based intervention in improving AWP-solving skills, while both CC and EM interventions are equally effective in reducing math anxiety. These results underscore the importance and the need of implementing structured cognitive strategies in classroom settings, which support text comprehension, problem representation, planning, and metacognition. Such an approach is essential for helping students learn to construct accurate mental models of problems—an area that requires greater emphasis in educational practices (Morin et al., 2017). Given the benefits of both CC and EM interventions, further research is needed to explore how EM can be integrated with cognitive strategies to support broader learning outcomes and a more comprehensive approach to math education.

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6. GENERAL DISCUSSION

Given the significant difficulties primary school children face in solving AWPs, the primary aim of this doctoral dissertation was to deepen our understanding of the individual factors contributing to children's AWP-solving ability and to explore how this skill can be effectively promoted. Through four distinct studies, this dissertation project extended previous research by adopting a more holistic approach resulting in investigating the role of both cognitive and emotional-motivational factors, particularly math anxiety (MA), providing novel insights into their unique contributions as well as their interactions in shaping AWP-solving performance.

Specifically, this dissertation addressed four critical research questions:

1. How do cognitive abilities—particularly executive functions, fluid intelligence, and reading comprehension—contribute to primary school children's AWP-solving and, more specifically, to the construction of a mental model?
2. What is the specific relationship between MA and AWP-solving, and how does MA and metacognitive experiences of perceived task difficulty influence AWP-solving?
3. How do MA, working memory, and ego-resiliency collectively influence children's performance on AWP-solving, and does their influence differ from that on arithmetic performance?
4. Do interventions aimed at reducing MA lead to improvements in AWP-solving skills, and how do these effects compare to those of a cognitive-focused intervention?

By addressing these questions, the present dissertation contributes both theoretical and practical advancements to the field of developmental and educational psychology. The findings clarify the independent and combined effects of cognitive and emotional-motivational factors on AWP-solving in children and provide evidence-based guidance for interventions aimed at improving AWP-solving skills in classroom settings. The novelty of this research lies in its comprehensive approach, integrating both cognitive and emotional-motivational dimensions, a critical perspective often neglected in previous studies focusing predominantly on cognitive factors alone.

6.1 Summary of the Results

The results across the four studies converge to show that children's AWP-solving is influenced by an interplay of cognitive and emotional-motivational variables. **Study 1** focused on the role of cognitive factors—specifically inhibition, updating, fluid intelligence, and reading comprehension—in predicting children's performance on AWPs, with particular emphasis on their role in problem representation. The literature has long emphasized the importance of problem representation (Hegarty et al., 1995; Lucangeli et al., 1998; Verschaffel et al., 2020; Yip et al., 2020), which refers to the process of forming an adequate mental model of the situation described by the problem. However, less is known about how different cognitive variables contribute to this process. To address this gap, we presented children with two types of AWPs: consistent and inconsistent problems, which differ in the cognitive demands placed on problem representation. In consistent problems, a relational term compares two sets, and this term is semantically aligned with the required arithmetic operation. In this case, children can use a direct translation approach, relying on keywords and creating a simpler propositional model to solve the problem. Conversely, inconsistent problems contain a relational term that is semantically misaligned with the required operation. To solve these problems correctly, children must engage in a more complex process of integration, constructing a coherent mental model that clarifies the relationship between the sets (de Koning et al., 2022). In this sense, inconsistent problems demand a shift from a superficial, keyword-based representation to a deeper, object-centered representation. The results of Study 1 indicated that inconsistent problems were significantly more challenging than consistent ones, underscoring the additional cognitive processes required for solving inconsistent problems. More importantly, the role of the cognitive factors varied based on the problem type. For consistent problems, fluid intelligence exerted both direct and indirect effects (through reading comprehension) on performance, while inhibition played a unique role as well. In contrast, for inconsistent problems, updating ability also became a significant factor alongside fluid intelligence, reading comprehension, and inhibition. These findings confirm the importance of cognitive control processes, such as inhibition and updating, in successful AWP-solving, and highlight the distinct contributions of each depending on the problem type and problem representation demands. Specifically, the ability to inhibit irrelevant information is critical for solving different types of problems (Passolunghi & Siegel, 2001), whereas the ability to update working memory representations seems to be particularly central for solving inconsistent AWPs.

Studies 2 and 3 extended the results from Study 1 by examining if and how emotional-motivational factors, particularly MA, influence AWP-solving in primary school children. While much of the previous research on MA has focused on calculation skills or general math achievement (e.g., Cuder et al., 2023; Korem et al., 2022) and on adult populations (e.g., Hart & Ganley, 2019; Skagerlund et al., 2019), this dissertation aimed to explore how MA specifically influences the more complex task of AWP-solving in younger students. Specifically, **Study 2** explored the relationship between MA, metacognitive experiences of task difficulty (i.e., how difficult the task is perceived to be), and AWP-solving performance in fifth graders, while also examining the role of gender. The results showed that MA is negatively related with AWP-solving performance, and that perceived task difficulty partially mediates this relationship. This suggests that MA should be recognized as a significant individual factor contributing to difficulties in solving AWPs (Lai et al., 2015; Passolunghi et al., 2019). More interestingly, the mediation effect suggests that a tendency to worry about mathematics might influence task-specific metacognitive experiences, leading students to perceive AWP-solving tasks as more demanding. Perceiving a task as highly difficult can negatively affect students' expectations of success (i.e., the higher the perceived difficulty, the lower their expectation of success; Eccles & Wigfield, 2020; Fulmer & Tulis, 2013), as well as their interest and enjoyment (Fulmer & Frijters, 2011; Nuutila et al., 2021), and their ability to self-regulate and choose effective strategies (Efklides, 2011). Moreover, according to some research, high evaluations of task difficulty are linked to a reduced willingness to engage with the task (Brehm & Self, 1989) and increased task avoidance (Atkinson, 1957). In this context, MA might act as an activator for negative on-task metacognitive experiences, potentially leading children to adopt less efficient problem-solving strategies that prioritize avoidance. Indeed, avoidance tendencies and behaviors are key indicators utilized in the diagnosis of anxiety and anxiety-related disorders (American Psychiatric Association, 2022). Thus, it can be speculated that the influence of MA on AWP performance, mediated by perceived task difficulty, reflects a broader pattern of avoidant behavior. Additionally, the results highlighted gender differences in MA, with girls showing higher levels of MA, although no significant gender differences were observed for perceived task difficulty or AWP-solving performance, aligning with the findings from Study 1 (where no gender differences emerged in solving consistent and inconsistent AWPs). These results underscore the need to consider gender when examining emotional-motivational factors in children’s math learning, particularly in relation to MA.

To further explore the role of MA in AWP-solving, **Study 3** examined the interplay between MA and cognitive factors (i.e., working memory) in children from grades 3 to 5. In addition, we sought to investigate the effects of protective personal assets, such as ego-resiliency, which is believed to help children cope with day-to-day challenges (Block & Block, 1980; Donolato et al., 2020). We were also interested in exploring the effects of these constructs on two distinct math tasks: AWP-solving and arithmetic skills. This study also addressed the limitations of Study 2 by controlling for general anxiety and age. Serial mediational analyses revealed three key findings. First, ego-resiliency had a positive indirect effect on math performance through two pathways: (1) MA, and (2) MA and working memory. These findings identify ego-resiliency as a potential protective factor in MA, suggesting that it may play an important role in mitigating the effects that challenges in math learning have. Therefore, when examining difficulties in math learning, it is crucial to consider broader temperamental factors, such as ego-resiliency. Including these factors can provide deeper insights into the varying responses that students display towards math learning

(Ramirez et al., 2018). Second, the study replicated previous findings showing that the cognitive factor of working memory partially mediates the relationship between MA and math performance. This is in line with the Processing Efficiency Theory (Eysenck & Calvo, 1992), which assumes that anxiety interferes with the cognitive resources required to solve tasks, resulting in poorer performance. This relationship represents a second mechanism through which MA affects problem-solving abilities. Moreover, findings have indicated a consistent pattern across AWP-solving performance and arithmetic performance. It is important to note, however, that the explained variance by the tested models varies between the two types of math skills. Specifically, the model explained a higher percentage of variance in arithmetic skills compared to AWP-solving, suggesting that additional variables may be relevant especially in accounting for AWP-solving performance (see Fuchs et al., 2018; Lin, 2021). Our study thus highlights the importance of investigating specific math abilities separately, as each may exhibit unique characteristics and may involve different processes. Overall, both Studies 2 and 3 emphasize the detrimental role of MA in AWP-solving performance.

Drawing upon the results of Studies 1, 2 and 3 in **Study 4** we designed, implemented, and compared the effects of two distinct interventions: a cognitive intervention and an emotional-motivational intervention. The cognitive intervention was designed to promote the cognitive components of AWP-solving (Mayer et al., 1984; Mayer & Hegarty, 1996), including text comprehension, problem representation, and planning, as well as metacognition. On the other hand, the emotional-motivational intervention was designed to enhance AWP-solving by targeting MA. It drew from previous intervention studies employing a cognitive-behavioral approach that integrated cognitive reappraisal, growth mindset principles and coping strategies, as well as metacognition (see Passolunghi et al., 2020). The aim was to evaluate the effectiveness of these interventions not only in improving AWP-solving performance but also in enhancing problem representation skills—the core component of AWP-solving (de Koning et al., 2022; Ng & Lee, 2009)—and reducing MA. Using multilevel modeling that accounted for classroom-level effects, we found that the cognitive intervention significantly improved AWP-solving performance, enhanced problem representation skills, and reduced MA, compared to the control group. The emotional-motivational intervention, while effective in reducing MA, did not result in significant improvements in AWP-solving performance or problem representation skills. These results suggest that although reducing MA may free up cognitive resources previously consumed by anxiety and stress, if students lack the necessary skills or knowledge, this will not automatically lead to better performance. This is consistent with the findings from Study 3, which showed that although MA is an important individual factor in AWP-solving, it explained only a modest amount of variance in AWP-solving, indicating that other specific cognitive factors might be more relevant in explaining AWP-solving performance. Furthermore, there was no significant difference between the two interventions in terms of reducing MA. These findings extend previous research (Fuchs et al., 2010, 2021; Passolunghi et al., 2020; Powell et al., 2020; Swanson et al., 2013) by highlighting the advantage of the cognitive intervention in improving AWP-solving abilities and underscore the importance of integrating structured cognitive strategies aimed at enhancing text comprehension, problem representation, planning, and metacognition into classroom instruction.

It is important to note, however, that the lack of a far-transfer effect from the emotional-motivational intervention on AWP-solving performance could be attributed to several factors. One possibility is that the posttest assessment was conducted too soon after the intervention, limiting the opportunity to observe any positive long-term effects. While the emotional-motivational intervention did not produce immediate improvements in AWP-solving abilities, this does not necessarily imply that such interventions are ineffective in the long term. It is possible that emotional-motivational interventions may take longer to influence cognitive and AWP-solving outcomes. Therefore, the findings should be interpreted with caution, and future research should include follow-up assessments to capture these potential delayed effects.

Together, the results across all four studies highlight that AWP-solving is a multifaceted process shaped by the interplay of cognitive abilities, emotional-motivational factors, and individual traits. However, efforts to improve AWP-solving ability by focusing solely on emotional-motivational factors, such as reducing MA, do not automatically enhance performance unless students also develop the necessary cognitive skills.

6.2 Theoretical Implications

Existing theoretical models of AWP-solving, such as the theoretical process model by Daroczy et al. (2015) described in the General Introduction (see section 1.1), have highlighted the importance of cognitive abilities as predictors of AWP-solving difficulties, neglecting however the crucial role of emotional-motivational factors. The findings from the four studies in this dissertation provide valuable contributions to these models by offering a more comprehensive perspective that integrates both cognitive and emotional-motivational aspects into a holistic framework. Overall, the results highlight that considering both cognitive and emotional-motivational factors is essential for improving our understanding of how individual characteristics explain difficulties in AWP-solving. The implications of these findings extend beyond simply adding new variables to existing models; they suggest a need for a paradigm shift in how we conceptualize AWP-solving. This task seems to require not only good cognitive abilities, but also a positive emotional approach. Below, we outline the implications for adjusting the existing theoretical models.

6.2.1 Emotional-Motivational Factors

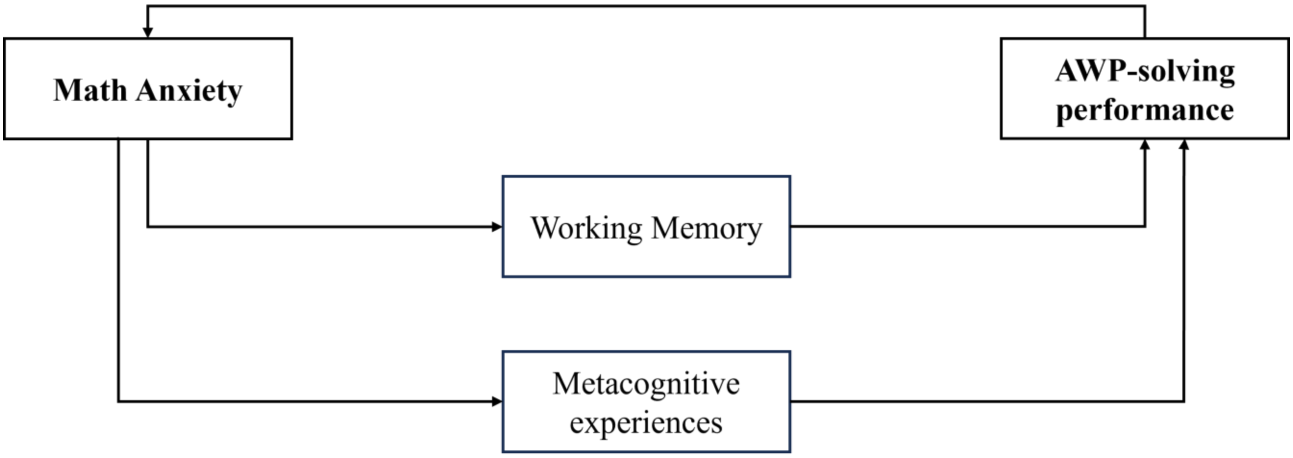
This dissertation underscores the significant role of emotional-motivational factors, particularly MA, alongside cognitive abilities, in contributing to difficulties in solving AWPs. Previous research has established a bidirectional relationship between MA and math performance, where high levels of MA lead to poorer performance, and lower performance, in turn, exacerbates feelings of MA (Gunderson et al., 2018; Szczygieł et al., 2024). This dissertation specifically aimed to understand how MA influences AWP-solving performance, revealing that MA negatively impacts performance both directly and indirectly through various mediating factors. One key mediator is working memory. As proposed by the Processing Efficiency Theory (Eysenck & Calvo, 1992), worries generated by MA consume working memory resources, leading to reduced performance (Pellizzoni et al., 2022). Another important mediator is students' metacognitive experiences of task difficulty. High levels of MA can create a self-reinforcing cycle: increased anxiety lowers confidence, which heightens perceived task difficulty and results in poorer problem-solving outcomes (Eccles & Wigfield, 2020; Efklides, 2011).

Thus, it could be hypothesized that MA influences performance through two main mechanisms (see Figure 6.1): (1) it depletes working memory resources, and (2) it affects metacognitive experiences, such as perceptions of task difficulty. These variables, in turn, may influence the strategies children use to solve AWPs. For example, heightened perceptions of difficulty due to MA can cause students to adopt less effective, avoidance-based strategies (Hanin & Van Nieuwenhoven, 2019, 2020). In a qualitative study by Hanin and Van Nieuwenhoven (2020) involving 22 primary school children, the researchers compared high and low problem solvers to understand how they managed challenges and negative emotions during problem-solving. When students were asked how they responded to difficulties or blocks, significant differences emerged between the two groups. High achievers consistently employed functional strategies that refocused their attention on the problem itself, while low achievers used a mix of functional and dysfunctional strategies, including negative distraction, avoidance behaviors, and negative self-talk. Similarly, MA seems to impair the use of advanced strategies, this is strategies that rely more heavily on working memory resources, causing students to rely on simpler, less cognitively demanding strategies. For instance, Cuder et al. (2023) found that children with higher levels of working memory were more negatively affected by MA in a math fluency task. As pointed out by Ramirez et al. (2016), suffering from MA would hinder the use of advanced memory-based strategies, leading high-working memory students who typically use those strategies to display worse math performance.

It is important to note, however, that more studies that employ a longitudinal or experimental approach are needed to provide more evidence on these mechanisms and support this theoretical perspective. Indeed, a major limitation of our study was the use of a correlational approach, which does not allow for causal inferences regarding the relationship between MA and AWP-solving performance. Moreover, our studies focused specifically on the role of MA, as it is a well-documented emotion with a significant impact on mathematical performance. However, to gain a more complete understanding of how emotional-motivational factors interact with cognitive and metacognitive aspects in influencing AWP-solving performance, future research should also investigate the role of other variables, such as math self-efficacy and math self-concept (Hoffman, 2010; Pajares & Miller, 1994; Živković et al., 2023).

Figure 6.1

Conceptual Framework Incorporating Metacognitive Experiences in the Vicious Cycle Between Math Anxiety and AWP-Solving Performance



Note. The figure illustrates the mechanisms through which math anxiety and AWP-solving performance influence each other. It is hypothesized that MA affects AWP-solving performance in the short term through two primary pathways: working memory, as described by the Processing Efficiency Theory (Eysenck & Calvo, 1992), and metacognitive experiences, as outlined in the

Metacognitive and Affective Model of Self-Regulated Learning (Efklides, 2011). These pathways, in turn, influence the problem-solving strategies children adopt. Specifically, a reduction in working memory capacity may lead to the use of less advanced, memory-based strategies, while negative metacognitive experiences can prompt more avoidant strategies. Furthermore, AWP-solving performance can have a reciprocal effect on MA, where lower problem-solving success contributes to increased levels of math anxiety.

6.2.2 The Role of Ego-Resiliency

In addition to cognitive and emotional-motivational factors, the findings from Study 3 introduce the concept of ego-resiliency as an important individual characteristic influencing AWP-solving indirectly through its impact on MA. By positioning ego-resiliency within the broader context of individual differences, this dissertation highlights the need for theoretical frameworks to consider how temperamental traits interact with emotional-motivational and cognitive factors in determining performance. Such a perspective can enhance our understanding of variability in MA and AWP-solving performance among children (Ramirez et al., 2018).

These insights align with the Interpretation Account of MA proposed by Ramirez et al. (2018). The Interpretation Account is based on findings that, although low math achievement and negative math learning environments are typically believed to cause MA (Luttenberger et al., 2018), there are instances where high-achieving students still exhibit high levels of MA. Conversely, some students who receive lower grades in math and share similar learning environments with those experiencing high MA do not necessarily develop math anxiety themselves (Lee, 2009). According to the Interpretation Account, the development of MA is largely shaped by how students interpret or appraise their past math experiences and outcomes, rather than the outcomes themselves. In this context, ego-resiliency may play a significant role in shaping how children interpret their math-related experiences.

Given that Study 3 this is one of the first studies to examine the relationships between ego-resiliency, MA, and AWP-solving, the findings open new avenues for research. Future studies should explore these interactions longitudinally to assess how ego-resiliency develops over time and influences MA and AWP-solving performance as children mature.

6.3 Practical Implications

The findings of this dissertation offer some important insights for practical applications in educational interventions, classroom instruction, and policy development, particularly in the design of targeted interventions for AWP-solving difficulties. Within the context of the three-tier model of support, which aims to address students' diverse academic and behavioral needs through progressively targeted levels of intervention, these findings are especially valuable for Tier I interventions. These focus on providing high-quality, universal support to all students. Emphasizing Tier I interventions can help create a positive learning environment that reduces the risk of AWP-solving difficulties and the development of negative emotions and attitudes. This approach aims not only to enhance AWP-solving skills across the entire student population but also to prevent the need for more intensive Tier II and Tier III interventions. Below, these implications are discussed in greater detail.

6.3.1 How to Enhance AWP-Solving Ability

If the goal is to reduce the AWP-solving achievement gap in primary school students, the results of Study 4 indicate that cognitive interventions are more effective than emotional-motivational interventions, particularly when considering short-term outcomes. Although emotional-motivational factors like MA can negatively impact AWP-solving (Doz et al., 2023, 2024; Lai et al., 2015), the task remains fundamentally a complex cognitive challenge that requires the engagement of multiple cognitive processes and abilities (Lin, 2021).

To design effective cognitive interventions, insights from Studies 1 and 4 are particularly valuable. Study 1 suggested the importance of constructing a coherent mental model of the problem. Constructing a mental model is crucial for comprehending the situation described in the problem, understanding relationships between sets, and ultimately selecting the appropriate arithmetic operation (Kintsch & Greeno, 1985; Ng & Lee, 2009). Thus, interventions that aim to strengthen children's ability to form accurate mental models could be especially beneficial in boosting AWP-solving skills.

Moreover, Study 1 highlighted the importance of domain-general cognitive abilities—such as inhibition, updating, and fluid intelligence—in supporting overall AWP-solving performance and in constructing a coherent mental model of the problem. Since constructing a mental model places significant demands on working memory and other executive functions, effective cognitive interventions should also aim to reduce cognitive load. Building on these results, Study 4 demonstrated that a cognitive intervention focusing on three core components—an attack strategy on deep comprehension of the problem's text, a visuo-spatial strategy for integrating and representing the problem situation, and strategic planning to manage cognitive load—yielded significant improvements. For instance, using visual aids like bar models can help children externalize the relationships between quantities, reducing the mental burden on working memory and facilitating better comprehension (de Koning et al., 2022; Ng & Lee, 2009; Powell & Fuchs, 2018). Such an approach aligns with the idea that reducing extraneous cognitive load enables students to allocate more cognitive resources to core problem-solving processes (Sweller, 1988).

Our newly designed cognitive-focused approach was more effective than traditional methods, such as the keyword strategy (Powell & Fuchs, 2018), which is still common in many educational contexts, including Italian schools. The keyword strategy encourages students to rely on surface features of the problem, such as specific words (e.g., "more than"), to determine the operation needed, without necessarily understanding the underlying structure or relationships within the problem (Hegarty et al., 1995). Although this method may be easier to teach and apply, it fails to support the problem representation needed for solving complex AWPs.

In sum, an approach that emphasizes the deep processing of the problem text, strategic use of visual aids to represent the situational model, and targeted support for strategic planning can better equip students to handle a variety of AWP types. This not only improves their immediate problem-solving abilities but also helps in developing a more flexible and adaptive approach to mathematical challenges, thus offering a more sustainable solution to bridging the AWP-solving achievement gap.

6.3.2 Emotional Wellbeing in Math Learning

If the aim is to improve wellbeing and positive attitudes in math learning, then results show that emotional-motivational interventions that target MA can be used as supplementary approaches to cognitive strategies, particularly for students who exhibit high levels of anxiety. Techniques such as anxiety-reduction strategies (e.g., reappraisal, mind growth principles, breathing work) and resilience-building activities may mitigate MA, thereby improving wellbeing in math learning.

Given that MA can impair math performance from an early age (Szczygieł et al., 2024), integrating strategies to reduce MA into the standard curriculum can mitigate its long-term effects. This is especially important because our research found that MA can emerge as early as primary school and significantly hinder AWP-solving performance at this stage (Doz et al., 2023, 2024). Early identification and intervention are thus essential for preventing lasting academic difficulties in mathematics. Educators should be trained to recognize the signs of MA and intervene appropriately. Study 4 highlights that it could be valuable to implement in classroom setting, throughout the school year, some activities, such as promoting growth mindsets, and addressing negative attitudes toward math, and teaching children coping strategies to reduce worries and negative emotions. By creating a supportive classroom climate, teachers can reduce the stigma associated with math failure and foster resilience in students.

Additionally, the documented gender differences in MA, with girls reporting higher levels of MA despite similar math achievement compared to boys (Devine et al., 2012; Doz et al., 2023; Goetz et al., 2013), suggest the need for gender-sensitive approaches. Tailoring interventions to address the specific emotional needs of different genders could be particularly effective in narrowing the gender gap in math-related fields. Moreover, efforts to challenge and dispel gender stereotypes about mathematical ability (Passolunghi et al., 2014) and to provide positive role models of successful women in STEM can help reduce the disproportionate impact of MA on girls, encouraging more equitable participation in math-related careers.

6.4 Conclusion

In conclusion, this dissertation underscores the importance of adopting a holistic approach to understanding and addressing AWP-solving difficulties in primary school children. By integrating cognitive and emotional-motivational factors, this work contributes to a more comprehensive model of problem-solving that has significant implications for both theory and practice. Moreover, this dissertation advocates for a shift in educational practices towards preventive measures rather than reactive solutions. By implementing early interventions at the Tier I level that focus on enhancing the core components of AWP-solving—reading comprehension, problem representation, planning, and metacognition—and teaching strategies to interpret challenges in math in a positive way, schools may mitigate the onset of AWP-solving difficulties and MA. Such proactive interventions may not only improve AWP-solving understanding but also instill enjoyment for learning among students, ultimately shaping their long-term educational trajectories.

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