INVESTIGATING THE RELATION BETWEEN WORKING MEMORY AND MATH ANXIETY AS CONTRIBUTORS TO ELEMENTARY STUDENTS' MATH TASK PERFORMANCE

by

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Investigating the Relation between Working Memory and Math Anxiety as Contributors to Elementary Students' Math Task Performance

Submitted by Meagan Murphy in partial fulfillment of the requirements for the degree of Master of Arts in School and Applied Child Psychology.

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Abstract

Math anxiety (MA) is a negative emotional response to mathematics with detrimental long-term consequences for math achievement. Although this math anxiety-achievement link is well understood in adulthood, less is known about MA and its relatedness to math performance and other cognitive variables in childhood. The present study aimed to determine the extent to which students in elementary school reported feelings of MA, whether reports differed by gender or grade level, and how these reports of MA were related to math performance on simple calculation fluency, multi-step calculation accuracy, and problem-solving tasks. Another goal of this study was to examine how MA interacted with working memory (WM) to contribute to math task performance. Students participated in two testing sessions, the first of which involved standardized tests of WM and math fluency, multi-step calculation, and word problem solving, followed by a second session where they completed a MA questionnaire. Nonparametric group comparisons revealed that MA scores were not significantly different between boys and girls or across grades. MA scores were correlated with performance on all math skills. MA scores were most strongly correlated with multi-step calculation, followed by problem solving and fluency. In addition, MA scores were most strongly correlated with verbal WM followed by visual-spatial WM. Moderation and mediation analyses were conducted to examine the relation between MA, verbal WM, and math performance, which revealed that verbal WM mediated the relation between math fluency and multi-step calculation ability, but not problem-solving. These findings have implications for our understanding of how students' math anxiety impacts their performance, highlighting the importance of discussing students' feelings about math with the aim of promoting student self-efficacy and reducing anxiety.

Lay Summary

Math anxiety (MA) is a negative emotional reaction some experience when faced with a math task. This research with students in grades 3 through 6 showed that some children report feelings of MA as early as elementary school, and that these feelings are related most closely to their ability to perform multi-step calculation questions, and to a lesser extent, their ability to solve math word problems and complete simple calculations quickly. In addition, children's MA reports were related to their verbal working memory (WM), or their ability to remember and work with information that they hear over a matter of seconds, suggesting that verbal WM may act as the link that explains the relation between math anxiety and math performance. Learning more about how MA is related to children's math performance will help to shape instructional strategies, interventions, and accommodations to better support students.

Preface

This thesis is the original and unpublished work of the author, Meagan Murphy under the supervision of Dr. Rachel Weber. The UBC Ethics Certificate number H17-00324 approved the work reported in the methodology and results sections of this thesis. The research design and analysis of research data was done independently by the author. Data collection and entry was completed by the author and Marley Morton, with the assistance of Raveena Mahal and Sarah Gutri.

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Introduction

Mathematical Difficulties

Research suggests that approximately 4 – 7% of school-aged children experience difficulty with mathematics (Fuchs, Compton, Fuchs, Paulsen, Bryant, & Hamlett, 2005). Without intervention, these difficulties can persist throughout an individual's lifespan (Geary, Hoard, Nugent, & Bailey, 2013). There is evidence to suggest that, as a whole, Canadians declined in their ability to perform multi-digit arithmetic quickly and accurately by 20% between 1993 and 2005 as provincial math curricula shift away from a focus on memorization (LeFevre, Penner-Wilger, Pyke, Shanahan, & Deslauriers, 2014). This fluency with basic calculation skills, however, is important in many aspects of daily life beyond an individual's academic performance in school. For example, some adults report not feeling comfortable calculating a tip at a restaurant or determining whether they receive the correct change when shopping (Maloney & Beilock, 2012).

Difficulties with mathematics can lead to avoidance of the subject, which ultimately acts as a career pathway "filter" (Ashcraft, 2002; Hembree, 1990). This "filter" becomes increasingly problematic given our society's need for skilled Science, Technology, Engineering, and Math (STEM) workers to accompany our escalating reliance on technology (Chipman, Krantz, & Silver, 1992). Proficiency in mathematics is not only important in STEM fields, but across all employment domains. Numeracy skills (i.e., the ability to understand and work with numbers) are associated with successful functioning within employment and progress towards promotion (Bynner & Parsons, 1997). Poor numeracy skills have been associated with lower levels of fulltime employment in adulthood, even after accounting for differences in literacy skills and years spent in school (Berlin & Sum, 1988; Parsons & Bynner, 1997). In addition, quantitative literacy, or the ability to apply mathematical skills when solving real-word problems, has been found to be associated with lower employment rates as well as lower earnings among those who are employed (Rivera-Batiz, 1992). In short, an individual's proficiency and willingness to engage with numerical concepts is closely associated with positive individual and societal outcomes. As such, efforts should be made to investigate various factors contributing to mathematics proficiency and avoidance.

Of particular interest at this time are the cognitive and affective underpinnings of math achievement. Traditionally, cognition and affect have been studied in isolation with regard to math achievement, however, research is beginning to investigate the interaction of these domains. Cognition occurs in the context of affect (Shields, Moons, Tewell, & Yonelinas, 2016), and in order for an intervention to be effective, it must address both of these factors. When considering math achievement specifically, for skill building interventions to be optimally successful, a student must be able to employ their learned skills without interference from negative emotions or attitudes. In addition, research on the cognitive profiles of students most likely to experience negative emotions or attitudes in response to mathematics will help to better customize interventions and classroom accommodations. Two of the most prominently researched cognitive and affective contributors to math achievement include working memory and math anxiety, respectively.

Working Memory

Working memory (WM) involves the capacity to temporarily store and manipulate information in one's mind while completing complex cognitive tasks (Baddeley & Hitch, 1974; Miyake & Shah, 1999). Mathematical competence requires students to hold numerical information in their mind while manipulating it to solve a problem. Arriving at a mathematical solution involves integrating conceptual understanding of a given mathematical domain, such arithmetic or geometry, with new information presented in a problem, all while performing the required procedures (Friso-van den Bos, van der Ven, Kroesbergen, & van Luit, 2013). Younger students, or students who do not yet have basic math calculations committed to long-term memory, must mentally perform these operations. As the math curriculum becomes more complex, students must hold much more information in mind while solving multi-step problems. Thus, WM capacity and efficiency is understandably imperative for developing and successfully executing mathematical skills (Bull & Scerif, 2001). WM capacity is also longitudinally predictive of mathematical achievement (Gathercole, Tiffany, Briscoe, & Thorn, 2005), and has been found to account for a significant amount of variance in math performance, even when controlling for IQ (Alloway & Alloway, 2010).

Further evidence for the role of WM in mathematics achievement comes from research involving populations of students who experience mathematical difficulties, such as those with Attention-Deficit/Hyperactivity Disorder or Learning Disabilities in mathematics, who often also demonstrate significant WM deficits (Maehler & Schuchardt, 2016; Menon, 2016). Research is inconclusive, however, regarding which components of WM are most related to math performance (Bull, Espy, & Wiebe, 2008; Friso-van den Bos et al., 2013; Gathercole, Pickering, Knight & Stegmann, 2004).

WM does not operate in isolation. Current research on WM and mathematical ability is beginning to explore how WM might interact with other cognitive and affective factors to contribute to academic performance, though there is much less research in this area involving elementary school-aged students. WM is a limited capacity system dependent on available resources, meaning there can be competition for its processing "power" at any given moment that may divert those resources away from task-related WM and, in turn, hinder task performance (Eysenck & Calvo, 1992). One such factor that may interact with student's WM when engaging in mathematical tasks includes their emotional response to the subject - specifically, their anxiety towards mathematics.

Math Anxiety

Math anxiety (MA) involves the "feeling of tension, apprehension or even dread, that interferes with the ordinary manipulation of numbers and the solving of mathematical problems" (Ashcraft & Faust, 1994). In the United States, approximately 25% of adults with a 4-year University degree experience MA to some extent, and this prevalence is estimated to be higher among adults who do not hold a University degree (Beilock & Willingham, 2014). MA is a global phenomenon, reported by individuals across cultures, and has been shown to be negatively related to math performance "within and across countries" even after controlling for economic factors (Foley, Herts, Borgonovi, Guerriero, Levine, & Beilock, 2017; OECD, 2013).

Little is known about how children experience MA, as the majority of this research has been conducted with post-secondary students (Ashcraft & Moore, 2009). Studies have shown that children as young as seven report experiencing MA (Ramirez, Gunderson, Levine, & Beilock, 2013), and MA tends to increase with age (Dowker, Bennett, & Smith, 2012; Krinzinger, Kaufmann, & Willmes, 2009). It is unclear, however, how prevalent reports of MA are among elementary students, and how this prevalence changes across elementary grades (Dowker, Sarkar, & Looi, 2016; Sorvo et al., 2017). Research with adults suggests that females report higher MA than males (Hembree, 1990; Hill, Mammarella, Devine, Caviola, Passolunghi, & Szűcs, 2016), though it is unclear at which age these gender differences begin to appear (Dowker et al., 2012; Sorvo et al., 2017). There are also conflicting results about whether MA is significantly associated with math performance amongst children (Hill et al., 2016; Ramirez, Chang, Maloney, Levine, & Beilock, 2016). This may, in part, be because the measure of math ability varies across studies of MA, with some assessing fundamental math skills such as arithmetic accuracy and fluency, others assessing complex word problem solving, or an aggregate math score. Research with younger samples is essential for better understanding the course of MA and its effects on math achievement, as well as developing early interventions for students most at-risk for MA and adverse math achievement outcomes. Comparing the contributions of MA across isolated math skills will help to clarify this association.

Research suggests many avenues by which MA impacts student achievement in mathematics. Longitudinally, MA impacts math performance in a “vicious cycle” where, over time, poor math performance may elicit MA and this anxiety, in turn, impacts future math performance (Carey, Hill, Devine, & Szücs, 2016). Other researchers seek to understand the cognitive effects of MA, which provides the basis for the current study, and is explained further in the following section.

The Relation between Math Anxiety and Working Memory within the Context of Mathematical Skills

As mentioned earlier, WM is a limited capacity system dependent on available resources, meaning WM processing about anything other than math may divert resources away from math-related processing and hinder math task performance (Ashcraft & Kirk, 2001). When considering MA specifically, the worries that accompany MA occupy WM resources, leaving fewer resources available to devote to math performance. In other words, MA creates a ‘dual task setting’ where math anxious individuals must divide their WM resources between their ruminations and the math task at hand, essentially multi-tasking (Beilock, Kulp, Holt, & Carr, 2004). According to this theory, performance on math tasks that are more reliant on WM would be more greatly impacted by the effects of MA. While much of the original research conducted by Ashcraft and colleagues involved adult participants, recent research by Owens and colleagues has demonstrated similar effects with adolescents when examining the effect of general anxiety on cognitive task performance (Owens, Stevenson, Norgate, & Hadwin, 2008). Processing efficiency theory research suggests that the relationship between MA and WM supports the use of a moderation model when conceptualizing how MA may affect may performance via its effect on WM. Recent research suggests that MA may display a differing relation with math performance across the range of WM ability, however, as studies have found that individuals with *higher* WM may be more susceptible to the effects of MA, because they are more likely to rely on "WM intensive" strategies to solve math problems (Dowker et al., 2016; Ramirez et al., 2013). This finding suggests that the relation between MA, WM, and math performance may be better represented as a moderation model, whereby MA and WM interact to contribute to math task performance.

It also currently unclear which components of the WM system are most closely associated with MA. Many studies indicate a general association across all WM processes, which, as Friso-van den Bos and colleagues (2013) state, is not unexpected given the integrative effects of Baddeley's central executive and episodic buffer. Some evidence exists, however, that general anxiety taxes verbal WM most heavily, as the ruminations that accompany anxiety require verbal processing (Owens et al., 2008). Other studies demonstrate the effect of MA solely on visuospatial WM (Crowe, Matthews, & Walkenhorst, 2007; Ganley & Vasilyeva, 2014; Mammarella, Hill, Devine, Caviola, & Szűcs, 2015). The association between MA and visuospatial WM may be especially relevant in the context of math, as visuospatial WM has been found to be most closely associated with math achievement earlier in one's schooling (Van de Weijer-Bergsma, Kroesbergen, & Van Luit, 2015). Students with lower WM may have fewer resources to spare in either or both of these domains and, as such, may be more susceptible to the effects of MA on math performance.

Additional research is needed to further explore the explanatory power of Ashcraft's theory in order to better conceptualize the cognitive effects of MA. As is the case in MA research more generally, studies examining the interactions between WM and MA have typically involved adult or high-school aged student samples. Research with younger students will better inform how the effects of MA impact cognition across the lifespan, as WM and math curriculum improve and progress with development. For example, younger students rely on WM for simple calculations, while adults may have committed this to long term memory and can retrieve the answer with rote automaticity. An understanding of how the cognitive effects of MA amongst children may be similar or different to that in adults is essential for developing effective early interventions for MA.

Purpose of the Present Study

The purpose of this study was to investigate the prevalence of self-reported math anxiety among elementary school students and how this math anxiety might interact with working memory to contribute to student math task performance. This study significantly contributes to the math anxiety literature, as it explores this construct among a thus-far understudied population. This study offers insight as to whether students in elementary school report experiencing math anxiety, and further elucidates the developmental trajectory of math anxiety across elementary school grades. This study also significantly contributes to the literature on academic intervention and achievement in mathematics by applying a framework in which to conceptualize the interaction of cognitive and affective factors as they contribute to student performance on math tasks.

Research Question 1. To what extent do students in grades 3 through 6 report feelings of math anxiety using the Adapted Modified Abbreviated Math Anxiety Scale (mAMAS)? How does the prevalence of these reports vary with demographic factors such as grade and gender?

Hypotheses. I hypothesized that elementary school students would report MA on the mAMAS. I hypothesized that girls would report higher mean mAMAS scores than boys. Grade level comparisons were done for exploratory purposes.

Research Question 2. To what extent is math anxiety associated with math task performance in this sample of elementary school students? How do these correlations compare when examining different subsets of math anxiety (learning or evaluation in mathematics) and math task complexity (calculation accuracy, fluency, and problem solving)?

Hypotheses. I hypothesized that MA would be correlated with math task performance, and that this correlation would be stronger for math tasks that rely more heavily on working memory, such as multi-step calculation accuracy and problem solving.

Research Question 3. Is the relation between working memory, math anxiety, and math performance better represented by a moderation or mediation model? Do these moderation or mediation effects differ when considering math task complexity (calculation accuracy, fluency, or problem solving)?

Hypotheses. I hypothesized that MA does not impact math performance directly, but instead does so in the context of WM, either by lessening the predictive effect of WM on math performance in a moderation model or occupying WM resources needed for math performance in a mediation model.

Literature Review

Mathematical Skills

Mathematical skills are a set of competencies learned in increasing complexity, including simple arithmetic, multi-step calculation, and problem solving. The consensus in the current mathematics literature is that these skills develop hierarchically, with lower level competencies necessary for developing higher level mathematical skills (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Fuchs et al., 2006). These skills are taught in the same ascending order in Canadian mathematics curricula, with students mastering basic skills before learning to apply them to solve problems. However, while lower order skills are necessary for higher level math thinking, they may not be sufficient. Fuchs and colleagues (2006) suggest that it may be more accurate to conceptualize math skills as a “partial hierarchy”, as they found that simple arithmetic skill was associated with both multi-step calculation and problem solving performance, but multi-step calculation was not significantly associated with problem solving performance. This indicates that problem solving, while requiring some knowledge of basic arithmetic, does not require an ability to “manipulate numbers procedurally” as in multi-step calculation, but instead may rely more heavily on other academic skills such as number sense and language ability.

Mathematics ability does not only rely on academic precursors but is also influenced by a number of cognitive abilities, as well as sociodemographic, biological, affective, and behavioural variables (as reviewed in Vukovic & Siegel, 2010). For example, gender is one such factor that was once believed to influence math achievement. While past research suggested a gender gap in math achievement, with male students outperforming females (Berlin & Sum, 1988), more recent research indicates that there are no significant gender differences in mathematics achievement (Voyer & Voyer, 2014). Despite these reports of comparable math achievement of male and female students, far fewer women than men are entering math-related careers and post-secondary education. In 2008, Canadian women represented only 26% of all doctoral graduates in mathematics, computing, and information science, 23% of graduates in engineering, and 42% in physical and life sciences (Marginson, Tytler, Freeman, & Roberts, 2013). In the case of gender, this lack of difference in achievement in mathematics raises the need to consider other factors that might act as "filters" to students entering STEM professions. A detailed discussion of all possible contributors to mathematics ability is beyond the scope of this project. However, the relation between working memory, the cognitive variable of interest, and math skills will be outlined in a later section of this chapter.

Research investigating individual student characteristics that contribute to math performance has produced somewhat inconsistent findings. A tendency to measure only one mathematical skill, create an aggregate score including differing math skills, or measure math skills in isolation without accounting for the contribution of lower order math skills to higher order skills may contribute to this inconsistency (Fuchs et al., 2006). It is estimated that 4-15% of elementary school-aged children experience significant math difficulty of some kind, whether this difficulty is a diagnosed learning disability or below-grade level mathematics performance without a formal diagnosis (Fuchs et al., 2005; Mazzocco & Myers, 2003; Vukovic & Siegel, 2010). When this significant difficulty in mathematics persists for longer than two years, students are more likely to experience long-term difficulties with mathematics throughout their schooling (Morgan, Farkas, & Wu, 2009). A student may experience difficulty at each level of the math skill hierarchy, either with fundamental arithmetic knowledge, the procedural aspects of multi-step calculation, or the applied nature of problem solving. Below, these mathematical skills are discussed in greater detail.

Simple Arithmetic Fluency. Arithmetic involves adding, subtracting, multiplying, and dividing single digit numbers (e.g., 4 + 5 = 9). Learning these skills follows a developmental trajectory, where students first develop counting skills (i.e. counting the two sets, then counting from the first number, and finally counting from the larger number). In a review of longitudinal studies of mathematics difficulty, Nelson and Powell (2017) found that several studies highlight early numeracy skills (including counting) in Kindergarten as significant predictors of persistent math difficulty. One longitudinal study found a child's counting ability in preschool to be more predictive of math achievement in grade two than visual attention, listening comprehension, and metacognitive understanding of effective learning strategies (Aunola et al., 2004). Once proficient with counting, students are then able to pair arithmetic problems with their answers in working memory. Eventually this association is stored in long-term memory, and children can retrieve known arithmetic facts quickly from memory (Fuchs et al., 2006). Fluency refers to how quickly and accurately children are able to retrieve the answers to simple arithmetic facts.

Multi-Step Calculation. Multi-step calculation involves the ability to add, subtract, multiply, or divide multi-digit whole numbers, decimals, or fractions (e.g., 391 + 327). Because these questions involve multi-digit numbers, they often contain more than one procedural step (e.g., to add 391 + 327, a student might first add 7 + 1, then 9 + 2, and finally carry the 1 for 1 + 3 + 3). It is difficult to determine the extent to which arithmetic ability contributes to multi-step calculation performance and the differential contributions both of these abilities make to mathematical problem solving ability as these two variables are often measured together in research (Fuchs et al., 2006). For this same reason, it is difficult to determine how these two math abilities are differentially influenced by individual student characteristics, such as cognitive and affective variables. In one study in which arithmetic ability was considered in a model with language, attention, and several cognitive variables including reasoning ability, working memory, long-term memory and processing speed, Fuchs and colleagues (2006) found that arithmetic ability accounted for a small but significant amount of variance in a student's multi-step calculation ability. So multi-step calculation difficulties might arise from a lack of competence with arithmetic or instead from challenges executing the procedural steps involved in these computations for a variety of reasons, including difficulties with attention or working memory (Fuchs et al., 2006).

Problem Solving. Mathematical problem solving is the ability to apply calculation skills and conceptual knowledge to solve linguistically presented problems (e.g., Ben had eight dog treats and wanted to give each dog an equal number of treats. How many would each dog get?). The hierarchical nature of mathematics learning suggests that difficulty with lower level math skills such as simple arithmetic and multi-step calculation will likely lead to difficulty with higher level skills such as problem solving. In addition, a student's problem solving ability may also be influenced by their language ability (Fuchs, Fuchs, Stuebing, Fletcher, Hamlett, & Lambert, 2008).

As discussed above, research suggests that a significant proportion of students will experience difficulty with mathematics that will persist throughout their school years into adulthood (Fuchs et al., 2005; Geary et al., 2013). Effective early intervention has the potential to raise the likelihood that students will pursue mathematics courses in their high school and post-secondary education (Lent, Lopez, & Bieschke, 1993), and ultimately increase their likelihood of full-time employment (Parsons & Bynner, 1997). A better understanding of student characteristics that may contribute to mathematical difficulty will aid in creating more effective interventions for students who are struggling with math early in their academic careers

(Clements & Sarama, 2011). One such student characteristic is working memory, which has been one of the most widely researched cognitive contributors to math ability.

Working Memory

` Working memory (WM) is the 'mental workspace' in which we hold relevant information in mind and work with this information to complete a task (Baddeley & Hitch, 1974; Diamond, 2013; Miyake & Shah, 1999). The most widely accepted model of WM put forth by Baddeley and Hitch (1974) originally involved three subcomponents; the central executive, visuospatial sketchpad, and phonological loop. The central executive works to coordinate, update, and attend to the visuospatial sketch pad and phonological loop, which temporarily offer limited capacity storage of visual and auditory information respectively (Baddeley & Hitch 1974; Miyake, Friedman, Emerson, Witzki, Howerter, & Wager, 2000). Factor analysis indicates that these visual and auditory domains can be conceptualized as separate components of WM in children as well as adults (Alloway, Gathercole, & Pickering, 2006). More recently, Baddeley (2000) proposed a fourth component known as the episodic buffer, which integrates information from WM components with long-term memory to create a single episodic memory of an individual's conscious experience.

The key component of WM that differentiates it from short-term memory is the ability to manipulate information held in mind rather than simply rehearsing it. Manipulating information in memory is necessary for schoolwork which requires students to engage in simultaneous effortful processes, such as holding instructions in mind while engaging in a task. As such, WM is considered more closely associated with academic achievement than short term memory (Siegel & Ryan, 1989; St Clair-Thompson, & Gathercole, 2006; St Clair-Thompson & Sykes, 2010). Longitudinal studies suggest that WM may even be more predictive of academic outcomes than intelligence (Alloway & Alloway 2010). WM is also imperative for learning as it is the 'portal to long-term memory' where learned information is stored for longer periods (Cowan, 2014). WM is so important for learning, in fact, that it is considered a cognitive risk factor for learning disabilities and difficulties (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Gropper, & Tannock, 2009; Moll, Göbel, Gooch, Landerl, & Snowling, 2016; Rogers, Hwang, Toplak, Weiss, & Tannock, 2011). While WM is imperative for learning across academic domains, the relations between WM and mathematical skills is of particular interest in the present study.

Working Memory and Mathematical Skills. Mathematical competence involves the ability to hold numbers in mind while performing mental operations to solve problems, and so it is not surprising that WM has been one of the most highly researched cognitive contributors to math ability. Generally, students with low WM scores have been found to display poorer performance in math computation and problem solving compared to their peers with higher WM performance (Alloway & Passolunghi, 2011; Bull & Scerif, 2001; Friso-van den Bos et al., 2013; Peng, Namkung, Barnes, & Sun, 2016). A recent meta-analysis by Peng and colleagues (2016) found a significant correlation between mathematics and WM (r = .35). Longitudinal studies add predictive power to this association as they offer evidence that WM predicts math performance in later school years (De Smedt, Janssen, Bouwens, Verschaffel, Boets, & Ghesquière, 2009; Passolunghi, Vercelloni, & Schadee, 2007; Swanson, & Beebe-Frankenberger, 2004). While the predictive contribution of WM to math ability may, to some extent, be shared with other executive functioning processes, WM has been found to predict unique variance in mathematical performance in the presence of other executive functions (inhibition and shifting), indicating that its predictive value is not simply due to its relations with other executive functions (Bull &

Scerif, 2001). While the link between WM and mathematical performance is well established in the literature, research is less consistent on the relative contributions of each component of WM to math performance.

Some studies suggest that mathematical skills have a more domain general reliance on WM than reading, which makes mathematics an especially interesting academic context in which to study WM. Specifically, while students with learning difficulties in both math and reading demonstrate phonological WM deficits in language, children with math learning difficulties also have been found to experience phonological WM deficits with numerical information, as well as visuospatial WM deficits (Bull et al., 2008; Gathercole, Pickering, Knight, & Stegmann, 2004; McLean & Hitch, 1999; Moll et al., 2016; Passolunghi, & Siegel, 2001; Pelegrina, Capodieci, Carretti, Cornoldi, 2015; Peng & Fuchs, 2016). Friso-van den Bos and colleagues (2013) suggest that, due to the integrative roles of the central executive and episodic buffer, it is to be expected that both visuospatial and phonological WM would be involved in mathematical performance, though their respective roles may shift as students age and progress in their math learning.

There is evidence to suggest that the role of WM in math performance may also vary with age. Generally, older students rely less on WM for simple calculations than younger students, who have not yet committed math facts to long-term memory (Imbo & Vandierendonck, 2007; Meyer, Salimpoor, Wu, Geary, & Menon, 2010). In addition, some studies have found that the relative involvement of the phonological and visuospatial WM components to math performance shifts during the primary grades (i.e., Grades 1-3). Specifically, both visuospatial and phonological WM were significant predictors of math ability for younger students, whereas only visuospatial WM remained a significant predictor for older students (Alloway & Passolunghi, 2011; Meyer et al., 2010). This shift in reliance from phonological to visual WM may reflect children's mental rehearsal of more simple calculations in their phonological loop, while the visuospatial sketchpad acts as a 'mental chalkboard' to visually lay out the more complex multi-step calculations learned in the later primary grades (Alloway & Passolunghi, 2011; Trbovich & LeFevre, 2003). However, other studies offer evidence of the opposite developmental shift, finding that the influence of visuospatial WM decreases as students age and illustrating the need for further research (De Smedt et al., 2009; Van de Weijer-Bergsma et al., 2015). These developmental changes in the contribution of WM to mathematical skills highlight the importance of studying the relations between these two variables with students in various stages of their math skill acquisition.

The current body of literature demonstrates a consensus that WM contributes to mathematical performance across studies including typically developing children, children with WM deficits, and children with math disabilities or difficulties (Raghubar, Barnes, & Hecht, 2010). Researchers are now looking for ways to further clarify the nuances of this association between WM and math performance. In their review of the literature on WM and math, Raghubar and colleagues (2010) call for a better specification of the WM and math skills being assessed in future research. These authors suggest that math skills (e.g., arithmetic, problem solving) be measured independently, rather than summarized by a single score representative of general math ability, and that WM be examined by modality (i.e. phonological, visuospatial) and skill (i.e. span maintenance or processing). Finally, researchers from both cognitive and affective fields emphasize the importance of considering cognitive abilities such as WM alongside emotional factors, as very few studies attempt to investigate the intersection of cognitive and affective factors in younger students (Cargnelutti, Tomasetto, & Passolunghi, 2017; Dowker et al, 2016). The current study will examine how WM interacts with math anxiety to influence math ability.

Math Anxiety

Math anxiety (MA) is a learned negative emotional response to mathematical stimuli (Ashcraft, 2002). Individuals who experience high levels of MA often experience feelings of tension, apprehension, or fear that interfere with their math performance (Ashcraft, 2002). Similar to a phobia, MA has been found to elicit physiological symptoms in response to anticipating or viewing mathematical stimuli, including an increased amygdala response and changes in cortisol, which are associated with threat detection (Hembree 1990; Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011; Pizzie & Kraemer 2017; Ramirez, Shaw, Maloney 2018). MA has been a topic of ongoing research since the term was first introduced by Dreger and Aiken (1957) to describe the "emotional disturbance" that many college students reported feeling in response to numbers and mathematics (Dowker et al., 2016). MA is typically assessed using self-report measures where respondents provide ratings on a continuous scale, though there is no agreed-upon criterion for how severe ratings must be to constitute a label of "math anxiety" (Dowker et al., 2016). Instead, researchers typically stratify scores into 'high' and 'low' MA groups according to scores one standard deviation above and below the sample mean, or the upper and lower quartiles of the distribution (Ramirez et al., 2018).

MA is not simply a reflection of a student's mathematical ability; rather, research suggests it is more closely related to other types of anxiety (Dowker et al., 2016). Despite these associations, MA is a distinct construct that is predictive of math performance even after controlling for these other types of anxiety (Hill et al., 2016). MA also appears to be distinct from anxiety towards academic achievement more generally. Lyons & Beilock (2012) observed these math-specific anxiety responses in an fMRI study, where students with high MA showed greater activity in brain regions associated with threat detection and the experience of pain in anticipation of engaging in math activities, but not reading activities.

Across MA research, studies differ in whether MA is conceptualized as a unitary construct, or one comprised of multiple factors. Many studies use a single self-report score as a measure of MA, though factor analysis of several MA scales has found that ratings fall into distinct sub-categories that differ according to the MA scale being used. Generally, sub-components of MA include anxiety about learning mathematics or situations involving math, and anxiety about evaluation or failure in mathematics (Carey, Hill, Devine, & Szűcs, 2017; Hopko, Mahadevan, Bare, & Hunt, 2003; Pletzer, Wood, Scherndl, Kerschbaum, & Nuerk 2016). Some research suggests that these two factors may have differential effects on math performance (Sorvo et al., 2017).

MA is a global phenomenon, though estimates of its prevalence vary according to the population sampled, the measure of MA used, and the criteria used to distinguish individuals as math anxious (Foley et al., 2017; Dowker et al., 2016). A report by the Organization for Economic Cooperation and Development on student self-beliefs about mathematics found that, on average, across the 41 participating countries, higher MA scores were associated with lower-than-average mathematics performance (OECD, 2013). However, some Asian countries, such as Korea and Japan, demonstrated an exception to this association, as students in these countries demonstrated both high MA and high math performance (Lee, 2009; OECD, 2013). The experience of MA is not limited to formal tests of mathematics, and has also been found to be adversely associated with financial literacy and financial planning ability, nurses' drug calculation accuracy, and teachers' self-efficacy as well as their students' math ability (Anthes,

& Most, 2000; Beilock & Maloney, 2015; Geist, 2015; Gresham, 2008; McKenna & Nickols, 1988; McMullan, Jones, & Lea, 2012; Ramirez, Hooper, Kersting, Ferguson, & Yeager, 2018; Skagerlund, Lind, Strömbäck, Tinghög & Västfjäll, 2018). Clearly, the detrimental implications of MA are diverse and wide-reaching in nature and thus merit continued investigation.

The majority of the existing research on MA has been done with secondary school-aged students and adults, with very few studies including elementary school-aged students (Eden, Heine, & Jacobs, 2013). The research that has been done with younger samples offers evidence that students as young as Grade 1 experience MA (Ramirez et al., 2013). The consensus in the literature is that MA increases as students age and progress through school (Dowker et al., 2012; Eden et al., 2013; Gunderson, Park, Maloney, Beilock, & Levine, 2018; Krinzinger et al., 2009). Details about this progression are unclear, including the age at which students begin to report MA and the rate at which it increases (Dowker et al., 2016; Sorvo et al., 2017). One study by Sorvo and colleagues (2017) found that a larger proportion of Grade 2 students reported MA than Grade 5 students. These authors found anxiety about failure in mathematics and anxiety about math-related situations to be distinct factors, with more Grade 4 than 5 students reporting anxiety about failure in mathematics (Sorvo et al., 2017). This suggests that the specific aspects of mathematics that cause students anxiety may shift as they progress through school.

Since MA is a learned response to mathematics, a student's level of MA is influenced by their own experiences with math, as well as the math-related expectations and attitudes of those around them, including parents and teachers (Beilock, Gunderson, Ramirez, & Levine, 2010; Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015). As such, the developmental progression of MA may be different for girls than boys. While there are currently no differences in math performance between women and men in countries that provide equal access to math education, there are still fewer women than men entering higher education and careers in STEM fields (Marginson et al., 2013; Spelke, 2005; Voyer & Voyer, 2014; Wang & Degol, 2017). This gender imbalance reflects stereotypical gendered expectations of men and women's attitudes and abilities with regard to math (Spencer, Steele, & Quinn, 1999). An examination of MA prevalence between men and women echoes this career trend, with women reporting higher levels of MA then men (Devine, Fawcett, Szűcs, & Dowker, 2012; Else-Quest, Hyde, & Linn, 2010; Goetz, Bieg, Lüdtke, Pekrun, & Hall, 2013; Hembree, 1990; OECD, 2013). It is important to note, however, that most anxiety disorders are diagnosed more frequently in girls/women than in boys/men at approximately a 2:1 ratio, according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-V; American Psychiatric Association, 2013). This gendered difference in MA reports is not seen as clearly in younger samples. Generally, research suggests that gender differences in mathematics do not emerge until adolescence (e.g., Devine et al., 2012; Harari, Vukovic, & Bailey, 2013), while some studies find MA gender differences in samples of first and second grade students (Gunderson et al., 2018; Sorvo et al., 2017). Research with elementary school-aged samples is essential in order to develop a better understanding of the developmental trajectory of MA for girls and boys.

Math Anxiety and Mathematical Skills. Another reason to investigate MA among younger samples is to better conceptualize how MA relates to math performance. It is reported in the adult literature that, typically, those who experience higher levels of MA also demonstrate more difficulty in mathematics (Devine, Hill, Carey, & Szűcs, 2017; Sorvo et al., 2017). In adolescents and adults, meta-analyses report negative correlations of around .3 between MA and math performance, however, this data is not yet available for elementary school-aged samples (Eden et al., 2013; Hembree, 1990; Ma, 1999). Some studies with children find an association between MA and math performance, similar to research with adults (e.g., Gunderson et al., 2018; Ramirez et al., 2016; Vukovic, Kieffer, Bailey, & Harari, 2013), while others do not find an association at all (Krinzinger et al., 2009; Ramirez et al., 2013), prompting researchers to hypothesize other factors that might influence the relation between MA and math achievement in younger samples. One reason that MA might have less of an impact on younger children's math performance is because these individuals have less opportunity to opt out of math courses and learning opportunities, as secondary school students and adults with MA often do (Ashcraft & Faust, 1994). However, one study by Cargnelutti and colleagues (2017) found a significant association between MA and math performance among Grade 3 students, but not Grade 2 students. Grade 3 students do not have much more autonomy over their opportunities to avoid math learning than those in Grade 2, so another explanation for this finding is that individual math skills are affected differently by MA. Given the scaffolded nature of mathematics curriculum, where basic math fact fluency is taught before multi-step calculation and problem solving, it could be hypothesized that the relation between MA and performance becomes stronger as the curriculum becomes increasingly complex. The ways in which MA may impact different math skills in different grades is discussed in the following section, where this relation is considered in the context of working memory.

In early MA research, there existed a "chicken or egg" problem, where researchers sought to understand whether individuals developed MA as a result of math difficulties, or if those with MA are more prone to math difficulties (Carey et al., 2016). Now researchers appear less concerned with parsing apart the directional effects of MA and math performance and instead view the relation as reciprocal while shifting their investigative focus to the mechanisms by which MA and performance are associated (Carey et al., 2016). Hembree (1990) found that individuals with MA tend to avoid math courses and learn less from the math courses they do take. This illustrates the two most researched ways by which MA and math performance interact, either by way of behavioural factors (e.g., avoidance), or by cognitive factors. As discussed above, of special interest in this study are the cognitive mechanisms that influence the relation between MA and math performance, specifically working memory.

Math Anxiety and Working Memory

Ashcraft and colleagues proposed the most widely accepted theory for how MA might interact with WM to impede math performance (Ashcraft, 1995; Ashcraft, 2002; Ashcraft & Faust, 1994; Ashcraft & Kirk, 2001). In his experiments, Ashcraft found that high and low MA individuals did not display significant differences in their math performance on basic one-digit addition or multiplication facts. Participants with high MA began to display impaired speed and accuracy compared to low MA participants, however, when math problems involved multi-step calculations such as carrying numbers for two-digit operations (Ashcraft 1995; Ashcraft, 2002). Consistent with processing efficiency theory (Eysenck & Calvo, 1992), Ashcraft proposed that the worries, ruminations, and intrusive thoughts associated with MA burden WM storage and processing capacity, leaving less resources to dedicate to math task performance (Ashcraft 1995, Ashcraft & Krause, 2007). He tested his theory by creating a ‘dual-task setting’ where participants were shown a span of letters, asked to perform single or double-digit calculation, and then to recall the letters. All participants had more difficulty remembering the letters when presented with a longer span and when required to perform double rather than single digit calculation, but participants with high MA demonstrated the most difficulty when compared to medium and low MA groups (Ashcraft & Moore, 2009). In other words, answering the math questions created greater limitations of the WM of individuals with high MA, presumably because engaging in the math tasks caused individuals to dedicate additional WM resources to their anxious ruminations.

When considering how MA affects WM, it raises the complementary question of how individual differences in WM might influence the effect of MA on math performance. The current literature is unclear with regard to how MA affects individuals across the spectrum of WM ability. The prominent view in past research is that individuals with low WM may be more susceptible to the effects of MA, as MA occupies valuable WM resources needed for math task performance, and those with lower WM have fewer resources to spare. Recent research challenges this perspective, however, as studies have found that individuals with *higher* WM may be more susceptible to the effects of MA, because they are more likely to rely on "WM intensive" strategies to solve math problems (Dowker et al., 2016; Ramirez et al., 2013). One study found that, among individuals with higher WM, their ability to perform under pressure in a fast-paced math task was influenced by MA. Specifically, in participants with high MA, increased arousal indicated by salivary cortisol was associated with worse performance, which the authors term as "choking under pressure", while those with low MA demonstrated improved performance in response to arousal (Mattarella-Micke et al., 2011).

Ashcraft's research, along with the majority of past research on the intersection between WM and MA, has been done with adults. Processing efficiency theory has been investigated with children, indicating that general anxiety has detrimental effects on WM and academic performance (Hadwin, Brogan, Stevenson, 2005; Owens et al., 2008). Cargnelutti and colleagues (2017) also found a negative correlation between math performance and general anxiety, but not math-specific anxiety, in a sample of Grade 2 students. This relation was stronger when examining performance on a higher WM math task (arithmetic) than on a lower WM estimation task (Cargnelutti et al., 2017). Recently, Moore & Ashcraft (2013) implore researchers to investigate the age at which MA ‘appears’ and begins to affect math performance, and researchers have begun to investigate the nature of the relation between WM and MA among elementary school-aged children. Similar to research with adults, Ramirez and colleagues (2013) found a negative correlation between MA and math achievement for Grade 1 and 2 students with higher, but not lower, WM. A study by Mammarella, Hill, Devine, Caviola, & Szűcs (2015) looks more closely at the individual WM domains, and found that students with math learning disabilities demonstrated specific deficits in visuospatial WM, while those with MA demonstrated specific deficits in verbal WM. These differential impairments in WM suggest that knowledge of the differing underlying cognitive implications of a student’s math difficulty are valuable in individualizing interventions and accommodations to the needs of each student.

The importance of investigating the early effects of MA on math performance is also evident when considering the changing reliance on WM in the developmental trajectory of math skill acquisition. Ashcraft found little effect of MA on performance on measures of basic one-digit calculation, however, there is reason to believe that children with MA would display impairment on these calculations as they may not yet have committed these answers to long-term memory and thus need to rely on WM to aid in solving even simple calculations. A study by Sorvo and colleagues (2017) provided initial evidence for this theory in finding that MA was related to even simple arithmetic fluency in Grade 2 students. Wu, Amin, Barth, Malcarne, and Menon (2012) offered the first evidence of the detrimental relation between MA and WM with elementary school-aged students when they found that MA was more strongly associated with decreased performance on a mathematical reasoning task than on a basic calculation task in a sample of Grade 2 students. The present study adds to these initial findings on the relation between WM and MA in elementary school children in order to more fully understand the early implications of MA on mathematics achievement.

Significance of the Present Study

This research investigates the prevalence of self-reported math anxiety amongst elementary school students in grades 3 through 6 in order to address the need for studies involving samples of younger students in the math anxiety literature. By collecting a sample of students across a range of grades, this research provides information necessary for understanding the developmental trajectory of math anxiety, and how the development of math anxiety may differ for boys and girls. Information regarding the age and gender of students at risk for math anxiety is essential for raising awareness about this phenomenon amongst educators and parents and working to prevent the lifelong consequences associated with math anxiety.

In addition, this research contributes to a better understanding of the age at which math anxiety becomes associated with math performance, as this is currently an area of inconsistency in the literature. Collecting information regarding student performance on math tasks of varying complexity helps to clarify which particular aspects of mathematics achievement are most closely related to math anxiety. In addition, examining the sub-categories of math anxiety, rather than simply regarding it as a unitary construct, aids in identifying which aspects of math (learning or evaluation) are worrisome for younger students, and how these might differentially relate to their math achievement. Understanding the nature of students' worries about mathematics allows teachers and parents to address these with greater specificity.

Finally, this study demonstrates the cognitive effects of math anxiety amongst elementary school students. By examining student performance on a variety of math tasks, including fluency, calculation, and problem solving, this research contributes to a more comprehensive understanding of how working memory interacts with math anxiety to contribute to math performance on increasingly complex math tasks. An improved understanding of how cognitive and affective factors interact to influence math achievement can aid in developing integrated early interventions and the ability to provide better individualized support for students struggling in mathematics.

Method

Participants

Ninety-four participants were recruited from three elementary schools in the Catholic Independent Schools Vancouver Archdiocese (CISVA) school district. Due to student absences and incomplete measures, data was available for 82 participants, however, only 68 of these participants completed the math anxiety measure. Missing data was handled using list-wise deletion. The sample of 68 students was composed of 50% girls ($N = 34$) and 50% boys ($N = 34$) in grades three (25%, $N = 17$), four (44%, $N = 30$), five (16%, $N = 11$), and six (15%, $N = 10$). Parent reports of ethnicity indicated that this sample was primarily composed of children of East Asian (52%, $N = 35$) and Southeast Asian (24% $N = 16$) ethnicities. To participate in the study, participants were required to be proficient in English and demonstrate intelligence (IQ) within two standard deviations of the normative mean (standard scores ranging from 70 to 130).

Procedures

Approval for this research was granted through the UBC Research Ethics Board and the CISVA school district. All testing took place at participating CISVA schools. Recruitment packages containing a written description of the study, an informed consent form, and a demographic questionnaire were sent home with students by participating classroom teachers in CISVA schools. Once parental permission was indicated via completed consent form, participant assent was obtained. Child participants, once assent was obtained, completed all measures according to the standardized procedures of each instrument. Testing took place across two sessions. The first session included an intelligence screener, the working memory and mathematics measures, and two executive functioning measures being used in a different study. Participants first completed the intelligence screener. The order of the remaining measures was administered according to one of two different procedures in order to minimize order effects. Half of the participants completed the two executive functioning measures, then the math tasks, and lastly the WM measure. The other half instead completed the WM measure before their math tasks and the executive functioning measures after their math. Participants were offered a short break halfway through this first session. During a second session held at least one week later, participants completed a short math anxiety questionnaire and a growth mindset questionnaire for another study. The math anxiety measures were administered in a separate session in order to avoid any distress that participants may experience by questioning them about their negative feelings with regards to mathematics immediately before or after having them complete a set of increasingly difficult mathematics assessments. Participants were given a small toy as compensation for their participation, regardless of whether they completed the entire testing session in full.

Measures

Demographic Information

Demographic Survey. The demographic survey included questions regarding each participant's gender, age, ethnicity, socioeconomic status (as measured by one parent's highest education level including high school, college, university, and post-graduate education) and any previous diagnoses of Specific Learning Disorder (SLD), Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorder (ASD), Developmental Coordination Disorder (DCD), Specific Language Impairment, (SLI) or any other relevant condition. Also, the survey requested information about participants receiving any academic interventions.

Intelligence

Kaufman Brief Intelligence Test—Second Edition (KBIT-2). The KBIT-2 is a brief, individually administered measure of verbal and nonverbal intelligence in children and adults. The KBIT-2 consists of 3 subtests and yields Verbal, Nonverbal, and a Composite IQ standard score. The test is designed for the purpose of screening intellectual abilities. The KBIT-2 has a large normative sample (N=2120), and has high internal consistency, split-half reliability, test-retest reliability, high reliability, and concurrent validity. The Composite IQ was used to determine if the participants met the inclusion criteria of having overall cognitive abilities within two standard deviations of the normative mean (IQ between 70 and 130).

Working Memory

Automated Working Memory Assessment: Short Form (AWMA-S). The AWMA is a standardized computer-based assessment of verbal and visual-spatial working memory for individuals 4-22 years of age. The AWMA was standardized using a normative sample of 1269 individuals from the United Kingdom and was found to have good to excellent test-retest reliability, good internal consistency, and good construct validity (Alloway, 2007). The short form of this measure includes four subtests: Digit Recall, Listening Recall, Dot Matrix, and Spatial Recall. Scores from the Listening Recall and Spatial Recall were used as verbal and visual-spatial working memory scores, respectively. Each participant had two separate standard scores, one for visual-spatial and one for verbal working memory.

Mathematics

KeyMath 3 Diagnostic Assessment: Canadian Edition (KeyMath 3). The KeyMath 3 is a standardized test of mathematics achievement that assesses basic concepts, operations, and applications. The KeyMath 3 was standardized in the United States using a sample of 3630 individuals aged 4 years 6 months to 21 years 11 months, with updated Canadian norms. The KeyMath 3 is a reliable and valid measure of mathematics achievement, with good internal consistency, test–retest, and alternate-form reliabilities, and good content and construct validity (Connolly, 2007). Participants completed the two Written Computation subtests (Addition & Subtraction and Multiplication & Division) and Applied Problem Solving. A calculation score produced by adding the scaled scores from the two Written Computation subtests (Addition & Subtraction and Multiplication & Division), as well as scaled scores from the Applied Problem Solving subtest were used in data analysis.

Simple Arithmetic Probe. Participants completed a timed set of single-step addition, subtraction, multiplication, and division questions in order to measure their ability to quickly and accurately solve simple calculations. Participants were told that they had 1 minute, and to try and solve as many questions as they are able in that time. A total raw score was used in data analysis.

Math Anxiety

Adapted Modified Abbreviated Math Anxiety Scale (mAMAS). The original AMAS (Hopko et al., 2003) was developed in the United States and used widely in math anxiety research with adult populations, including samples of Canadian adults (e.g. Maloney, Risko, Ansari, & Fugelsang, 2010). This modified version of the AMAS was adapted by Carey and colleagues (2017) in order to demonstrate that math anxiety can be validly and reliably measured in children using this instrument. Carey and colleagues (2017) piloted the mAMAS with a sample of 1849 students in England aged 8-9 and 11-13 years old. The total mAMAS has very good internal consistency, and its subscales both have good internal consistency. The mAMAS has good construct validity and shows divergent validity from tests of general anxiety and test anxiety. On the mAMAS, students were asked to rate how anxious or worried they would feel during various situations involving mathematics on a 5-point Likert-type scale ranging from 1 (low anxiety) to 5 (high anxiety). Carey and colleagues (2017) labeled these lower and upper scale limits with a sad and happy face cartoon respectively, however, the current study instead used circles of increasing size as visual aids to represent varying amounts of anxiety, in order to be consistent with another questionnaire used with these students. Scale instructions and situational questions were read to children by examiners and the words "worry" or "nervous" were used in place of "anxiety", due to the various reading abilities present across the age range of the sample. The mAMAS is made up of two subscales, Math Learning (5 items, with scores ranging from 5-25) and Math Evaluation (4 items with scores ranging from 4 – 20); total mAMAS scores range from 9 – 45.

Analyses

Before addressing the research questions, a one-way between subjects analysis of variance (ANOVA) was conducted to examine the effect of SES on WM and the three dependant variables: math fluency, calculation, and problem solving. This preliminary analysis was done to determine whether SES should be included as a predictor in the regression models for the third research question. In order to meet the assumptions of a one-way ANOVA, homogeneity of variance and normality of the dependant variable across levels of the independent variable were checked using a Levene's test and Shapiro-Wilk tests respectively. In addition, correlational analyses were performed to explore the associations between all variables involved in the three research questions.

The first research question involved examining the extent to which students in grades 3 through 6 reported feelings of math anxiety and how the prevalence of MA reports varied across gender and grade. Descriptive statistics provided an overall picture of the prevalence of MA reports. MA was found to violate the assumption of normality across gender and grade groups, and as such, non-parametric tests were used to compare groups. A Mann-Whitney U test was conducted to compare MA scores between boys and girls, and a Kruskal-Wallis H test was conducted to compare MA scores across grades. Histograms and boxplots of MA scores across gender and grade were visually examined, which revealed that the shape of the distribution of MA scores were not similar across gender and grade groups. As such, the mean ranks of each distribution of MA scores were compared, rather than the median of each group.

To address the second research question, correlations were examined to determine the extent to which MA is associated with math task performance. Specifically, MA scores, including total anxiety, anxiety about learning mathematics, and anxiety about mathematics evaluation were correlated with math task performance on each of the skills assessed (fluency, calculation, and problem solving).

The third research question called for an investigation of a possible moderation or mediation model describing the interaction between MA, WM, and math task performance. The procedure for the analysis of a moderation model is discussed first below, followed by the discussion of mediation analysis. Prior to conducting moderation and mediation analyses, the assumptions of multiple regression were checked. Independence of residuals for all three models was assessed by examining the Durbin-Watson statistic, for which all values should be between 1.5 and 2.5. The assumption of linearity was examined using scatterplots for each of the three models. The assumption of homoscedasticity was assessed by visual inspection of a plot of studentized residuals versus unstandardized predicted values for each model. The data was examined for outliers or influential data points, using the criteria of leverage values less than 0.3

and Cook's D values less than 1. The assumption of normality of residuals was checked using visual examination of a histogram and a P-P plot of the standardized residuals.

Moderation Analyses. A moderator is a variable that influences the strength or direction of a predictive relation, analogous to the way in which a "dimmer switch" adjusts the intensity of lighting (Wu & Zumbo, 2008). I hypothesized that MA may lessen the predictive effect of WM on math performance. Specifically, increasing MA might dampen the strength of the association between WM and math performance, as students with higher MA have less WM resources to dedicate to the math task at hand. A hierarchical multiple regression was used to investigate the interaction between WM and MA as they contribute to math performance. The hierarchical nature of this analysis allowed for the inclusion of blocks of predictors in order to build a set of successive linear regression models. Comparing the variance accounted for by these models allowed for an investigation of whether predictors in a later block accounted for a significant amount of variance over and above earlier blocks. Verbal WM scores were used in moderation analyses, as these were found to be more closely associated with MA scores and math task performance than visual-spatial WM.

To determine whether MA had a moderating effect on the relation between Verbal WM and math performance, both Verbal WM and MA were included in the first block of the regression model, with math performance as the dependant variable. If these variables both explained a significant amount of the variance in math performance, a second model was entered that included Verbal WM and MA, as well as a Verbal WM by MA interaction term. If this model accounted for significantly more variance than the first model and the interaction term is significant, it could be said that MA had a moderating effect on the relation between WM and math performance.

Three hierarchical regressions were conducted, one for each mathematical skill assessed (fluency, calculation, and problem solving). In the analysis examining math fluency, age was entered in the first sequential block, as these scores were not standardized according to age. In addition, MA was not a significant predictor in the model for math fluency, and as such, the Verbal WM by MA interaction term was not added to this model. Figure 1 below illustrates the general conceptual model and the order of the sequential blocks for moderation analysis.

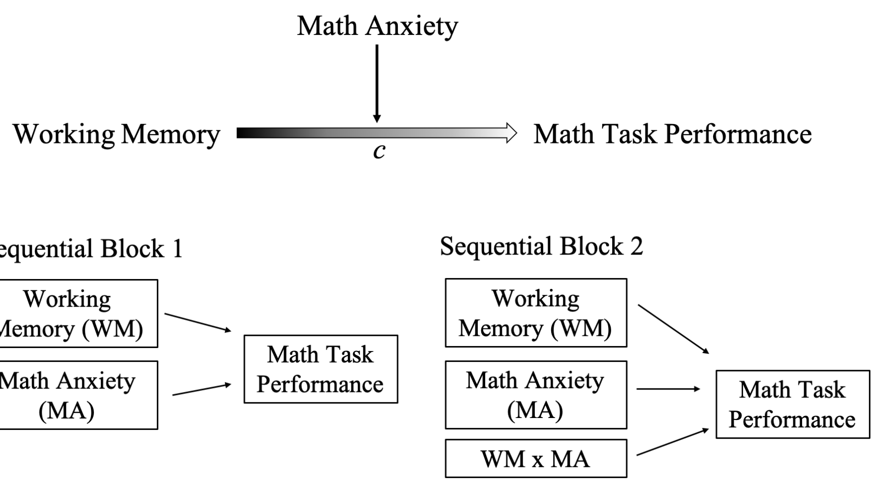

Figure 1. Conceptual diagram (top) and hierarchical regression model (bottom) proposed to examine the moderating effect of math anxiety on the relation between working memory and math task performance.

Mediation Analyses. A mediator is a variable that represents the intermediate 'link' by which the IV causes the DV. While the IV cannot impact the DV itself, it does so through the mediator, similar to a series of falling dominos (Wu & Zumbo, 2008). I hypothesized that while MA does not impact math performance directly, it does occupy WM resources needed for math task performance, thus impacting math scores. A series of regression analyses was used to investigate this mediation model, based on Baron and Kenny's (1986) four step method. First, a regression was run to demonstrate a relation between the independent variable (IV) and dependent variable (DV). Secondly, a regression was run with the mediator as the dependent variable, to demonstrate the relation between the IV and the mediator. The final regression included both the IV and mediator as predictors of the DV. The third step involved examining this final regression to determine whether the mediator remained a significant predictor of the DV. In the fourth step, this same regression was examined to determine whether the IV no longer significantly predicted the DV. If all four of Baron and Kenny's (1986) conditions are met, this is known as "full mediation". If only the first three conditions are met, then this is known as "partial mediation". Bootstrapping the standard error of the mediation effect was used to test the significance of the mediation. Mediation analysis and significance testing was done using the PROCESS macro for SPSS (Hayes, 2012). The figure below illustrates the general conceptual model and Baron and Kenny's (1986) steps for the analysis of Verbal WM as a mediator of the relation between MA and math task performance. In the model for simple calculation fluency, age was be added as a covariate, because fluency scores were not standardized for age.

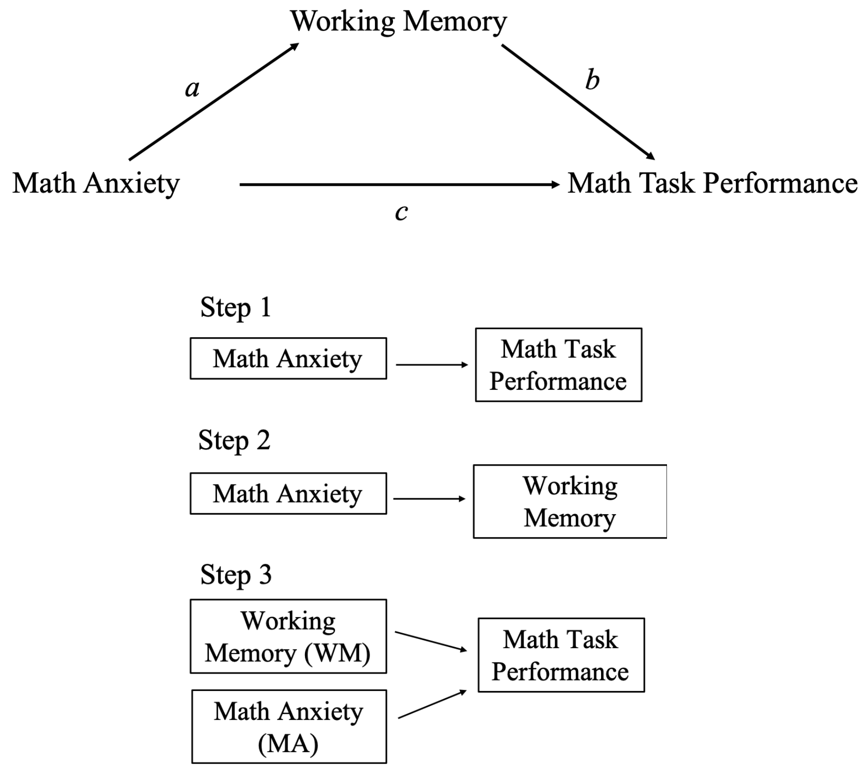

Figure 2. Conceptual diagram (top) and regression model (bottom) proposed to examine the mediating effect of working memory on the relation between math anxiety and math task performance.

Results

Before addressing the research questions, a one-way between-subjects analysis of variance (ANOVA) was conducted to examine the effect of SES on WM and the three dependant variables: math fluency, calculation, and problem solving. A Bonferroni adjustment was used, in which the significance levels from the Least Significant Difference (LSD) multiple comparisons were multiplied by the 5 tests performed. A Levene's test of homogeneity of variance and Shapiro-Wilk tests of normality of the dependant variables (math skills, WM) across the levels of SES were not statistically significant, indicating no homoskedasticity or normality assumption violations. There was no significant effect of SES on math skills or WM performance. Table 1 below includes a summary of these ANOVA results.

Table 1.

One-Way ANOVA of Parent Education Levels by Math Skills and WM

	Sum of Squares	df	Mean Square	*F*
Math Fluency				
Between Groups	66.49	3	22.16	0.25
Within Groups	4519.01	50	90.38	
Total	4585.50	53		
Calculation				
Between Groups	14.69	3	4.90	0.21
Within Groups	1192.15	50	23.84	
Total	1206.83	53		
Problem Solving				
Between Groups	28.53	3	9.51	1.11
Within Groups	420.71	49	8.59	
Total	449.25	52		
Verbal WM				
Between Groups	760.73	3	253.58	1.07
Within Groups	11873.64	50	237.47	

Total	12634.37	53		
Visual-Spatial WM				
Between Groups	1039.12	3	346.37	1.74
Within Groups	9961.92	50	199.24	
Total	11001.04	53		

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

A correlational analysis was also conducted prior to addressing the research questions. Intercorrelations among variables are presented in Table 2, and central tendency data are presented in Table 3. The correlational analysis revealed that SES was not significantly correlated with any of the dependent variables (math skills), and therefore it was determined that SES would not be included as a predictor in the multiple regression models. In addition, the analysis revealed that verbal WM was correlated with all math skills, while visual-spatial WM was only correlated with multi-step calculation and problem solving. MA was significantly correlated with all math skills. MA scores were also significantly correlated with verbal WM, but not visual-spatial WM. Both types of WM were significantly correlated with one another.

Table 2.

Intercorrelations for Predictor and Outcome Variables

	1	2	3	4	5	6	7
1. SES	-						
2. Math Fluency	0.04	-					
3. Calculation	0.04	0.54**	-				
4. Problem Solving	0.16	0.26*	0.62**	-			
5. Verbal WM	0.24	0.31**	0.45**	0.56**	-		
6. Visual-Spatial WM	0.26	0.16	0.24*	0.45**	0.52**	-	
7. MA	0.04	-0.27*	-0.54**	-0.42**	-0.29*	-0.13	-

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

Table 3.

Means, Sample Size, and Standard Deviations for Predictor and Outcome Variables

Variables	*N*	*M*	*SD*
1. SES	54	2.56	0.86
2. Math Fluency	68	14.96	9.12
3. Calculation	68	21.13	4.81
4. Problem Solving	65	11.45	2.87
5. Verbal WM	68	101.12	14.99
6. Visual-Spatial WM	68	110.41	14.68
7. MA	68	19.75	7.54

Research Question 1

The first research question addressed the extent to which the participants reported feelings of MA using the Adapted Modified Abbreviated Math Anxiety Scale (mAMAS), and how the prevalence of these reports varied with demographic factors such as grade and gender. The mean score for the Evaluation subscale was 11.09 (*SD*=4.33) and for the Learning subscale was 8.66 (*SD*=4.02). A Shapiro-Wilk test showed that mAMAS scores were not normally distributed (Total scale: $W_{(68)}$=0.92, p<0.01; Learning subscale: $W_{(68)}$ =0.82, p<0.01; Evaluation subscale: $W_{(68)}$=0.94, p<0.01). The distribution of total mAMAS scores was positively skewed with a skewness of 0.92 (standard error=0.29). The distribution of the learning subscale is positively skewed, with a skewness of 1.57 (standard error=0.29), and positively kurtosed, with a kurtosis of 2.36 (standard error=0.57). Despite violating the Shapiro-Wilk test of normality, the distribution of the evaluation subscale did not demonstrate significant skew (skewness=0.38, standard error=0.29) or kurtosis (kurtosis=-0.95, standard error=0.57). Distributions of the total and subscale scores can be seen in Figure 3 below, and median scores for total and subscale scores are included in Table 4.

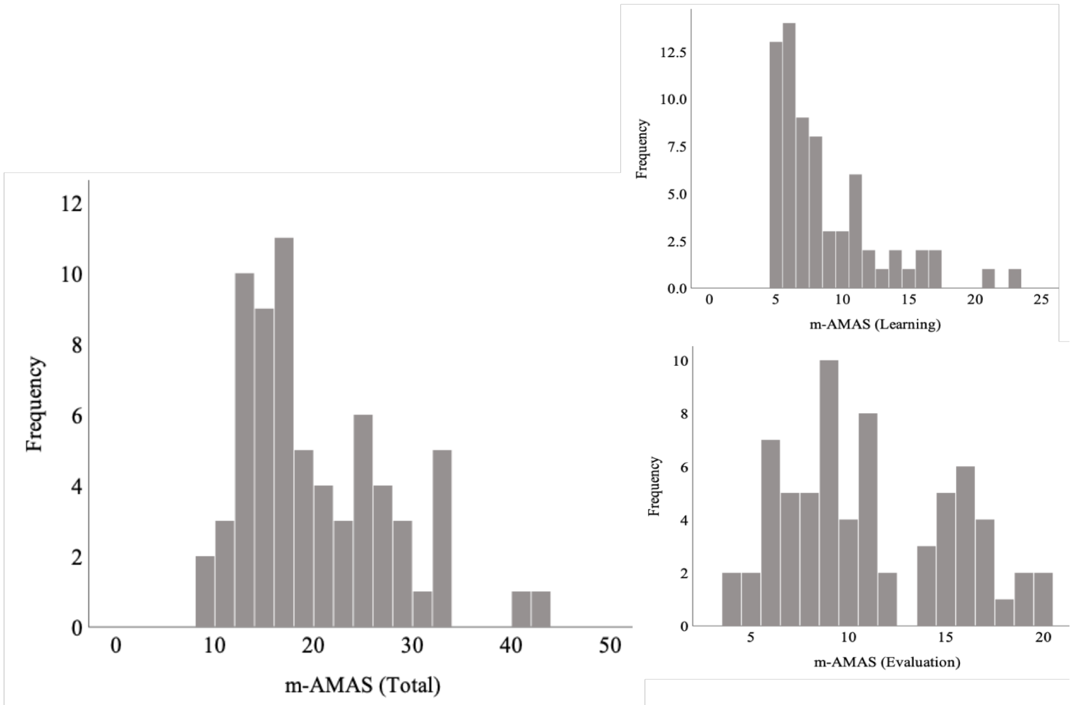

Figure 3. *Distributions of Total and Subscale MA Scores*

Table 4.

Descriptive Statistics for Total and Subscale MA Scores

Variables	*Minimum*	*Maximum*	*Mean*	*Median*	*Range*	*SD*
1. MA (Total)	9	42	19.75	17	33	7.54
2. MA (Learning)	5	23	8.66	7	18	4.02
3. MA (Evaluation)	4	20	11.09	10	16	4.33

A Mann-Whitney U test was run to determine if there were differences in MA scores between boys and girls. Distributions of MA scores for boys and girls were not similar, as assessed by visual inspection of a boxplot (See Figure 4). There was no statistically significant difference in total MA scores or learn and evaluate subscale scores between gender groups U_{Total}=535.50, z=-0.52, p=0.60; U_{Learn}=507, z=-0.88, p=0.38; U_{Eval}=476, z=-1.26, p=0.21. A Kruskal-Wallis H test was run to determine if there were differences in MA scores across the grade groups. Distributions of MA scores were not similar for all groups, as assessed by visual inspection of a boxplot (see Figure 5), but the distributions of MA scores were not significantly different across grades $H(3)_{Total}$=4.49, p= 0.21; $H(3)_{Learn}$=7.74, p= 0.05; $H(3)_{Eval}$=3.12, p=0.37.

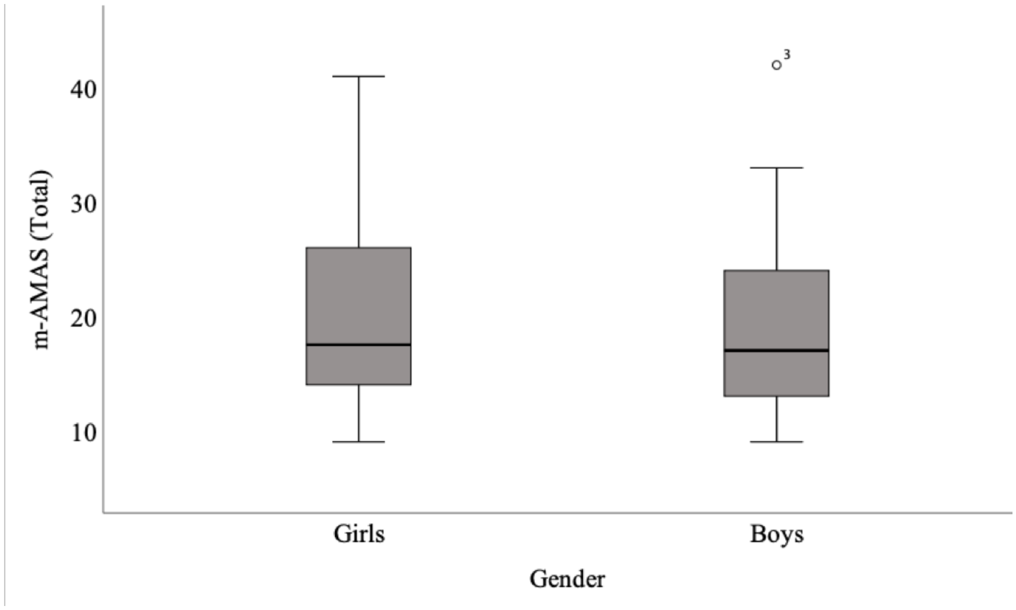

Figure 4. *Comparison of MA Scores Across Gender*

N=68 (34 girls, 34 boys)

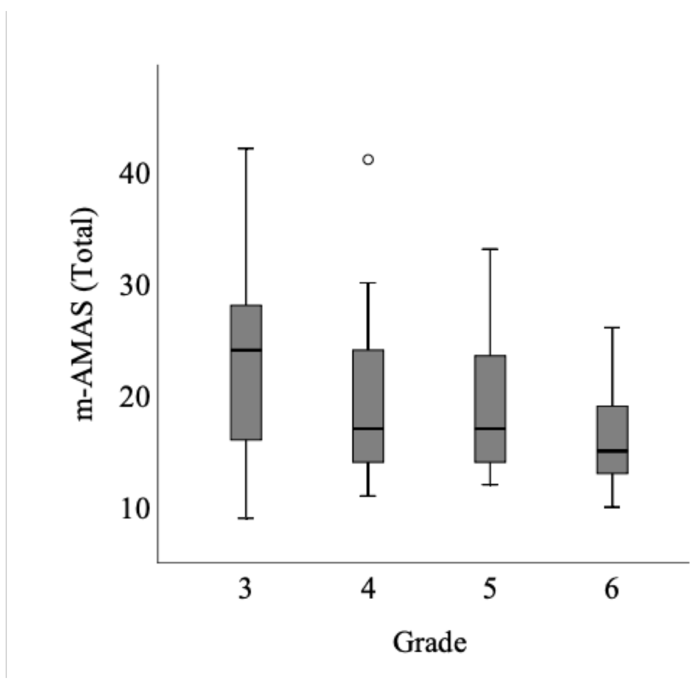

Figure 5. *Comparison of MA Scores Across Grade*

N=68 (Grade 3: *N*=17, Grade 4: *N*=30, Grade 5: *N*=11, Grade 6: *N*=10)

Research Question 2

The second research question asked the extent to which students' MA scores were associated with their math task performance. This question was addressed by examining the correlations between MA total and subscale scores with math fact fluency, multi-step calculation accuracy, and problem solving performance (see Table 5). The analysis revealed that total MA scores were significantly negatively correlated with math fact fluency, calculation, and problem solving performance. Both total and subscale MA scores were more closely associated with multi-step calculation and problem solving than fact fluency.

Table 5.

Intercorrelations for MA and Math Skills

	1	2	3	4	5	6
1. Math Fluency	-					
2. Calculation	0.54**	-				
3. Problem Solving	0.26*	0.65**	-			
4. MA (Total)	-0.27*	-0.54**	-0.42**	-		
5. MA (Learning)	-0.21	-0.44**	0.35**	0.90**	-	
6. MA (Evaluation)	-0.29*	-0.54**	-0.40**	0.91**	0.63**	-

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

Research Question 3

The third research question inquired as to whether the nature of the association between WM, MA, and math task performance was best represented as a moderation or mediation model. Total MA scores were used in the following analyses, as there were no significant differences found in the correlations between Learning and Evaluation subscales and math performance (as seen in Table 5 above). Verbal WM scores were used, as these were found to be more closely associated with math anxiety scores than visual-spatial WM (as seen in Table 5).

Moderation Analyses.

The assumptions of multiple regression analysis were met for all three models (fluency, calculation, and problem solving). WM and MA variables were centered to avoid multicollinearity problems with the interaction term. After centering, the assumption of multicollinearity was checked using VIF scores and was met for all three models.

Simple Calculation Fluency. This model included two sequential blocks, with age in the first block, and Verbal WM and MA in the second block. Regression statistics are reported in Table 6. The results of the hierarchical regression revealed that the model for block one was significant, F (1, 66) = 33.30, p <0.001, accounting for 34% of the variance in simple calculation fluency performance. The model for block two was also significant, F (3, 64) = 19.12, p <0.001, accounting for 47% of the variance in performance. Age (β = 0.59, p <0.001) and Verbal WM (β = 0.32, p <0.05) were significant predictors in this model. MA was not a significant predictor, and as such, the Verbal WM by MA interaction term was not added to the model for simple calculation fluency.

Table 6.

Hierarchical Regression Analysis for Verbal WM and MA Predicting Simple Calculation Fluency

Variable	β	R	R^2	ΔR^2
Block 1		0.58	0.34	0.34
Age	0.58***			
Block 2		0.69	0.47	0.14*
Age	0.59***			
Verbal WM	0.32*			
MA	-0.11			

N=68, *p<0.05, **p<0.01, ***p<0.001

Multi-Step Calculation Accuracy. This model consisted of two sequential blocks, with the first block containing Verbal WM and MA, and the second block containing Verbal WM, MA, and the Verbal WM by MA interaction term. Regression statistics are reported in Table 7. The results of the regression revealed that the model for the first block was significant, F (2, 65) = 20.64, p <0.001, accounting for 39% of the variance in multi-step calculation performance. The model for the second block was also significant, F (3, 64) = 13.56, p <0.001, but did not account for any additional variance over and above the first block. Both Verbal WM (β =0.32, p < 0.01) and MA (β = -0.46, p <0.001) were significant predictors in this model, however the Verbal WM by MA interaction term was not significant.

Table 7.

Hierarchical Regression Analysis for Verbal WM, MA, and Verbal WM by MA Interaction Predicting Multi-Step Calculation Accuracy

Variable	β	R	R^2	ΔR^2
Block 1		0.62	0.39	0.39
Verbal WM	0.32**			
MA	-0.45***			
Block 2		0.62	0.39	0.00
Verbal WM	0.32**			
MA	-0.46**			
Verbal WM x MA	-0.02			

N=68, *p<0.05, **p<0.01, ***p<0.001

Problem Solving. This model consisted of two sequential blocks, with the first block containing Verbal WM and MA, and the second block containing Verbal WM, MA, and the Verbal WM by MA interaction term. Regression statistics are reported in Table 8. The results of the regression revealed that the model was significant, F (2, 62) = 27.22, p < 0.001, accounting for 47% of the variance in problem solving performance. The model for the second block was also significant, F (3, 61) = 18.70, $p < 0.001$, but did not account for a significant amount of additional variance over and above the first block. Both Verbal WM ($\beta = 0.54$, $p < 0.001$) and MA ($\beta = -0.33$, $p < 0.01$) were significant predictors in this model, however the Verbal WM by MA interaction term was not significant.

Table 8.

Hierarchical Regression Analysis for Verbal WM, MA, and Verbal WM by MA Interaction Predicting Math Problem Solving

Variable	β	R	R^2	ΔR^2
Block 1		0.68	0.47	0.47
Verbal WM	0.55***			
MA	-0.29**			
Block 2		0.69	0.48	0.01
Verbal WM	0.54***			
MA	-0.33**			
Verbal WM x MA	-0.12			

$N = 65$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Mediation Analyses.

Simple Calculation Fluency. Regression analysis revealed that MA was significantly negatively associated with simple calculation fluency ($\beta = -0.21$, $p < 0.05$), that MA was significantly associated with verbal WM ($\beta = -0.30$, $p < 0.05$), and that the mediator, verbal WM, was significantly associated with simple calculation fluency ($\beta = 0.32$, $p < 0.01$). Regression statistics are reported in Table 9. Because the relation between MA and verbal WM, as well as the relation between verbal WM and simple calculation fluency were both significant, mediation analyses were tested using the bootstrapping method with bias-corrected confidence estimates (MacKinnon, Lockwood, & Williams, 2004; Preacher & Hayes, 2004). A 95% confidence interval of the indirect effects was obtained with 5000 bootstrap resamples (Preacher & Hayes, 2008). Verbal WM remained a significant predictor of fluency in the presence of MA (verbal WM β=0.32, p<0.01), and MA was no longer a significant predictor of fluency in the presence of verbal WM (MA β=-0.11, p<0.24), suggesting the presence of a complete mediation effect. This mediation effect was significant (completely standardized indirect effect = -0.10, Bootstrapped CI = -0.20, -0.01) as the bootstrapped confidence interval did not contain 0.

Table 9.

Mediation Analysis for Verbal WM as a Mediator of the Relation between MA and Simple Calculation Fluency

Effect	β	R	R^2
Total effect of MA on Fluency		0.62	0.38
MA	-0.21*		
Age	0.56***		
Direct effect of MA on Fluency in the presence of verbal WM		0.69	0.47
MA	-0.11		
Verbal WM	0.32**		
Age	0.59***		
Indirect Effect of MA on Fluency via verbal WM			
MA	-0.10		

N=68, *p<0.05, **p<0.01, ***p<0.001

Multi-Step Calculation Accuracy. Regression analysis revealed that MA was significantly negatively associated with multi-step calculation accuracy (β=-0.54, p<0.001), that MA was significantly associated with verbal WM (β=-0.29, p<0.05), and that the mediator, verbal WM, was significantly associated with multi-step calculation accuracy (β=0.32, p<0.01). Because the relation between MA and verbal WM, as well as the relation between verbal WM and multi-step calculation accuracy were both significant, mediation analyses were tested using the bootstrapping method with bias-corrected confidence estimates (MacKinnon, Lockwood, & Williams, 2004; Preacher & Hayes, 2004). Mediation statistics are reported in Table 10. A 95% confidence interval of the indirect effects was obtained with 5000 bootstrap resamples (Preacher & Hayes, 2008). Verbal WM remained a significant predictor of multi-step calculation in the presence of MA (verbal WM β=0.32, p<0.01), and MA remained a significant predictor of calculation in the presence of WM (MA β=-0.45, p<0.001), suggesting the presence of a partial mediation effect. This mediation effect was significant (completely standardized indirect effect = -0.09, Bootstrapped CI=-0.17, -0.01) as the bootstrapped confidence interval did not contain 0.

Table 10.

Mediation Analysis for Verbal WM as a Mediator of the Relation between MA and Multi-Step Calculation Accuracy

Effect	β	R	R^2
Total effect of MA on Calculation		0.54	0.29
MA	-0.54***		
Direct effect of MA on Calculation in the presence of verbal WM		0.62	0.39
MA	-0.45***		
Verbal WM	0.32**		
Indirect Effect of MA on Calculation via verbal WM			
MA	-0.09		

N=68, *p<0.05, **p<0.01, ***p<0.001

Problem Solving. Regression analysis revealed that MA was significantly negatively associated with math problem solving performance (β = -0.42, p <0.001), MA was significantly associated with verbal WM (β = -0.25, p = 0.047), and the mediator, verbal WM, was significantly associated with problem solving performance (β = 0.55, p <0.001) in the presence of MA. Regression statistics are reported in Table 11. Because the relation between MA and verbal WM, and the relation between verbal WM and problem solving were both significant, mediation analyses were tested using the bootstrapping method with bias-corrected confidence estimates (MacKinnon, Lockwood, & Williams, 2004; Preacher & Hayes, 2004). Verbal WM remained a significant predictor of problem solving in the presence of MA (verbal WM β=0.55, p<0.001), and MA remained a significant predictor of problem solving in the presence of verbal WM (MA β=-0.29, p<0.01), suggesting the presence of a partial mediation effect. However, an examination of the 95% confidence interval of the completely standardized indirect effects with 5000 bootstrap resamples indicates that this mediation effect was not significant (indirect effect=-0.14, Bootstrapped CI=-0.27, 0.01) as the bootstrapped confidence interval contained 0.

Table 11.

Mediation Analysis for Verbal WM as a Mediator of the Relation between MA and Math Problem Solving

Effect	β	R	R^2
Total effect of MA on Problem Solving		0.42	0.18
MA	-0.42***		
Direct effect of MA on Problem Solving in the presence of verbal WM		0.68	0.47
MA	-0.29*		
Verbal WM	0.55**		
Indirect Effect of MA on Problem Solving via verbal WM			
MA	-0.14		

N = 65, *p < 0.05, **p < 0.01, ***p < 0.001

Discussion

The first objective of this study was to determine the extent to which students in grades 3 through 6 report feelings of MA using the mAMAS, and how these reports vary with gender and grade. The second objective was to determine the extent to which MA is associated with elementary school students' math task performance on simple calculation fluency, multi-step calculation accuracy, and problem solving. The third objective was to examine whether the relation between WM, MA, and math task performance is better represented by a moderation or mediation model.

Regarding the first objective of this study, I hypothesized that elementary school students would report MA on the mAMAS. Although there are no predetermined 'cut-off' points for what constitutes high and low MA on the mAMAS, the distribution of total MA scores in this sample is similar to that found by Carey and colleagues (2017) in their study testing the reliability and validity of their modified version of the AMAS for use with children (mAMAS). In these authors' large sample (N=1746) of British students ages 8-13, the average mAMAS scores were M_{Total}=19.67 (*SD*=7.65), M_{Learn}=9.19 (*SD*=4.17), and M_{Eval}=10.48 (*SD*=4.32), which are remarkably comparable to the sample in the present study (students aged 8-12) M_{Total}=19.75 (*SD*=7.54), M_{Learn}=8.66 (*SD*=4.02), and M_{Eval}=11.09 (*SD*=4.33). Both samples demonstrated positively skewed total and subscale scores, with the greatest skewedness seen in learning subscale scores. In other words, more students reported MA scores on the low end of the scale than on the higher end, though there was more variation in student ratings regarding their anxiety about being evaluated in math than about learning math more generally. Though few students rated their MA at the higher end of the scale, these findings contribute to the recently growing body of literature that children as young as elementary school report feelings of MA (Carey et al., 2017; Cargnelutti et al., 2017; Ramirez et al., 2013; Sorvo et al. 2017; Vukovic et al., 2013). These similarities are especially interesting given the demographic differences between the Carey and colleagues' British sample and the present sample of Canadian students of primarily East and Southeastern Asian ethnicity, supporting the consensus in the literature that MA is a cross cultural phenomenon (Foley et al., 2017; OECD, 2013). In addition, these findings provide initial evidence for Carey and colleagues (2017) claim that this scale is acceptable for use with English speaking elementary school students outside of the UK.

The first objective of this study also aimed to examine differences in MA across age and grade. I hypothesized that, like adults, girls would report higher average mAMAS scores than boys, and grade comparisons were done on an exploratory basis. Contrary to my hypotheses and the consensus in the adult literature, there were no significant differences in MA scores between boys and girls. These findings also contradict the findings of Carey and colleagues (2017), in which elementary school-aged students girls reported significantly higher MA scores than boys. However, the findings of Carey et al. 2017 were less straightforward with regard to MA across grades. These authors found that only scores on the evaluation subscale, and not total MA scores or learning subscale scores, were significantly higher for students in late elementary (year 7 and 8) than early grades (year 3 and 4). In the present study, there were no significant differences in MA scores across grades. It is possible the findings of Carey et al. were not replicated due to the present study being underpowered. Although MA scores did not differ across grades in the present study, the positively skewed MA scores seen in both the present sample and that in the work of Carey and colleagues (2017) differs from the normally distributed sample of AMAS scores found by Hopko and colleagues (2003) in their adult sample, suggesting that, by adulthood, the majority of individuals report moderate levels of MA. This difference in distribution between child MA scores in the present study, and the distribution of adult MA scores in the work of Hopko and colleagues (2003) illustrates the consensus in the literature that MA increases with age on a broad scale (Dowker et al., 2012; Eden et al., 2013; Gunderson, Park, Maloney, Beilock, & Levine, 2018; Krinzinger et al., 2009).

The second objective of this study concerns the extent to which MA is associated with elementary school students' math task performance. I hypothesized that MA would be correlated with math task performance on fluency, calculation, and problem-solving tasks, and that this correlation would be stronger for higher level math tasks, such as multi-step calculation and problem solving. Consistent with my hypothesis, MA total scores were negatively associated with math performance across all math tasks. This is consistent with research that has found a significant relationship between MA and calculation fluency (Sorvo et al. 2017) and word problems (Gunderson et al., 2018; Vukovic et al., 2013). However, Hill and colleagues (2016) found that the association between MA and arithmetic performance did not remain significant for an elementary school student sample after controlling for general anxiety. General anxiety was not measured in the present study, and as such, it is impossible to parse apart MA from general anxiety in these results. In addition, results of the present studied demonstrated that anxiety about being evaluated in math was more closely related to math task performance than anxiety about learning math. This could be because the measures used to assess math achievement were individually administered math tests. Perhaps anxiety about learning math might affect students over a longer time scale, as it influences their willingness to engage in opportunities to learn and practice mathematics.

Fluency scores showed only a small correlation with MA scores, problem solving had a small to moderate correlation, and calculation showed a moderate correlation. These correlation sizes are consistent with meta-analytic reports of correlations around 0.3 between MA and math performance for adolescents and adults (Eden et al., 2013; Hembree, 1990; Ma, 1999). These findings are also consistent with adult research, which suggests that multi-step calculation performance is more affected by MA than simple calculation fluency, as individuals are able to draw simple calculations from long-term memory (Ashcraft 1995; Ashcraft, 2002). The present correlational results were inconsistent with my hypothesis that problem solving would demonstrate the highest correlation with MA as the highest-level math skill. Perhaps the various linguistic factors involved in problem solving performance contributed to the weaker correlation with MA than multi-step calculation, particularly among the present sample of primarily Asian-Canadian students, for many of whom English may not be their first or only language.

The third and final objective of this study was to explore the relation between WM and MA as contributors to math task performance. Much of the literature on the relation between WM and MA considers the interaction through the lens of processing efficiency theory, whereby MA related worries occupy WM resources needed for math task performance (Ashcraft 1995, Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007, Beilock et al., 2004). Both a moderation and mediation model were applied to the data to determine how to best characterize the relation between MA, WM, and math performance. Prior to exploring each model type, the correlation between MA and WM was examined, which revealed a nonsignificant negative correlation between MA and visual-spatial WM, but a small negative correlation between verbal WM and MA. These results are inconsistent with research that claims that MA occupies visual-spatial WM resources to impact math performance, given the proposed role of visual-spatial WM in math learning (Crowe et al., 2007; Mammarella et al., 2015). Instead, these results are consistent with processing efficiency theory, which proposes that anxiety impacts tasks performance by disrupting verbal WM, because anxious ruminations are processed in the phonological loop (Eysenck & Calvo, 1992; Owens et al., 2008). For this reason, verbal WM was entered into moderation and mediation models rather than overall WM or visual-spatial WM scores. Verbal WM also demonstrated stronger correlations with student performance on all math tasks, though visual-spatial WM did display small to moderate correlations with calculation and problem solving respectively. Given the strong relation between verbal WM and math performance, it follows that students with lower verbal WM scores also reported higher MA scores. It may be the case that students with lower verbal WM have a more difficult time with acquiring mathematical skills, which heightens their anxiety towards the subject.

An examination of MA as a moderator of the relation between verbal WM and math performance did not support my hypothesis that MA lessens the predictive effect of WM on math performance, as the verbal WM by MA interaction term was not significant predictor for any of the three math skills. This is inconsistent with past moderation models (Ramirez et al., 2013; Vukovic et al., 2013) that have found that MA shows a stronger negative relationship to math performance for students with higher WM than for those with lower WM. The positive skew of MA scores in the present sample may have limited the possibility of observing an interaction if one does exist. Most MA scores were on the low end of the possible range of scores, making it more difficult to observe interactions between the full range of 'high' and 'low' MA with 'high' and 'low' WM.

An examination of mediation models for each math skill indicated that the relation between MA and math performance might be better conceptualized as being mediated by WM. WM was found to fully mediate the effect of MA on simple math fluency, and to partially mediate the relation between MA and multi-step calculation ability. There was no mediation effect found in the model for problem solving. This is likely because as the type of math task becomes increasingly complex, there are a greater number of additional factors contributing to student performance. For example, Fuchs and colleagues (2006) demonstrated that simple arithmetic, nonverbal problem solving, concept formation, sight word efficiency, and language all significantly contribute to math problem solving performance. The significant mediation effects for simple calculation fluency and multi-step calculation accuracy are consistent with research by Owens and colleagues (2008) of verbal WM, but not visual WM, as a mediator between elementary aged children's general anxiety and math performance on a standardized assessment task.

General Conclusion

In conclusion, this study demonstrated that Canadian elementary school students showed a similar distribution of MA scores on the mAMAS as the British sample used by Carey and colleagues (2017) to test the validity and reliability of their newly adapted children's MA scale. In the present sample, however, there were no significant differences between average MA scores reported by girls and boys, or across grades. This new MA questionnaire is adapted from the most widely used adult MA questionnaire, and the only MA questionnaire that is appropriate for the full 8 to 13-year age range (Carey et al., 2017), and thus, exploring the utility of the mAMAS is important for learning about the changing nature of MA over the course of development.

MA scores were significantly negatively associated with math performance across all math tasks, demonstrating the strongest correlation with multi-step calculation, followed by problem solving and simple calculation fluency. MA scores were found to be more closely correlated with verbal WM than visual-spatial WM. Verbal WM was found to fully mediate the relation between MA and simple calculation fluency, and partially mediate the relation between MA and multi-step calculation accuracy. These results are consistent with processing efficiency theory (Eysenck & Calvo, 1992) whereby a student's negative ruminations about mathematics are processed in the phonological loop, leaving less verbal WM resources to dedicate to mentally walk through the steps of both simple and multi-step math calculations.

Implications for Practise

This mediation model provides a framework for educators and researchers to conceptualize how cognitive and affective factors relate to mathematics achievement as early as elementary school. The finding that students' self-reported MA is related to their performance in fundamental math skills as early as elementary school provides a rationale for teachers to discuss with students their feelings about mathematics and work to promote student self-efficacy and reduce anxiety. These early efforts to reduce anxiety are especially important for students with learning disabilities in the area of math, as the relation between math performance and anxiety suggests that this subset of students who face especially persistent math difficulties may be at a higher risk for developing MA.

Reducing children's MA involves parents and teachers modeling positive attitudes towards mathematics for students and avoid expressing negative attitudes which, as Dowker and colleagues (2016) discuss in their review of the MA literature, may be difficult if parents or teachers are themselves anxious about mathematics. The findings of the present study underscore the importance of early intervention on MA and make a case for further intervention research, as there is currently a lack of consensus in the literature regarding effective MA intervention. One promising intervention involves expressive writing, wherein students write out their ruminations with the aim of unburdening working memory resources. Ramirez and Beilock (2011) demonstrated the effectiveness of this intervention at improving test performance for university students with test anxiety. Park and colleagues (2014) found that this intervention significantly reduced the difference in math test performance between high school students with 'high' and 'low' level MA. Further research is needed to explore whether an expressive writing intervention is similarly effective amongst elementary school students.

Limitations

Perhaps the most significant limitation of the present study is its observational design. Wu and Zumbo (2009) emphasize that when applying a mediation model to observational data, the experimenter is unable to claim directionality, as it may be equally likely that poor math performance and poor verbal WM predict MA. In addition, these authors discuss the requirement for "precedence control", or measuring the IV before measuring the mediator and then the DV, in mediation study design, as without this temporal sequence, it is possible that the relation between WM and math achievement is due to another third variable that has nothing to do with MA. For example, although intelligence scores were used to ensure that participating students had an average IQ, intelligence was not controlled for in mediation and moderation models, and it is unknown how accounting for intelligence would affect the relation between MA and verbal WM, as well as MA and math performance.

Several other limitations of the present study are related to the nature of the sample. It is possible that students with high levels of MA may have self-selected out of a study that involved several math tests. Additionally, the sample was composed of primarily East and Southeast Asian participants (76%), which is a much higher percentage than is representative within the general population of Vancouver (31%; Statistics Canada, 2016). These students were also recruited from private schools where parents pay tuition, which may have contributed to the lack of variability in the SES of the sample, as most participants were of middle to higher income homes. For these reasons, no generalizations should be made beyond the ethnicities, SES, or grades of the participants in the sample. Further, although there were no significant differences in MA scores across grades, it is worth noting that no conclusions can be drawn about the development of MA based on a cross-sectional sample. Longitudinal data on a cohort of students would be needed to make claims about how MA and its relation with WM and math performance changes throughout a student's schooling.

When interpreting the findings of the present study, it is essential to consider the limitations of the measures used to define the constructs of WM, MA, and math performance. The mAMAS is a newly modified children's MA scale, so as the authors mention, it would be useful to have children complete another measure of math anxiety to determine the convergent validity of the mAMAS, however there is no existing MA scale appropriate for the complete (8-13 years) age range of the mAMAS (Carey et al., 2017). In addition, many MA studies include a measure of general anxiety and some also include a measure of test anxiety. These other measures of anxiety were not included in the present study, making it impossible to parse MA apart from general anxiety and test anxiety in this sample. It is possible that students with higher general anxiety reported higher MA scores. In addition, although the questions on the mAMAS ask students to think of how "worried" they would be when faced with various math-related situations, it is possible that children are rating their dislike or avoidance of the subject. It could be that students with lower math ability and verbal WM find mathematics more difficult and as such are rating their dislike of the subject, rather than a true experience of anxiety. However, it could be argued that this early dislike and avoidance for mathematics will further exacerbate these students' difficulties with math, and so these attitudes should be addressed regardless of how they are labeled. Finally, considering MA and WM as the only contributors to math performance is an oversimplified model of math performance, and including other factors in the model may change the relation between MA and WM as they contribute to math skills. Fuchs and colleagues argue that many other factors should be controlled for when examining math performance, including lower level math skills, language, processing speed, and attention, among other factors (Fuchs et al., 2006). Finally, the sample performed within the average range on all norm-referenced measures of math and WM, which did not provide an opportunity to examine groups of students with particularly high or low math or WM performance. This is noteworthy for interpreting MA results, as there is evidence that the relation between MA and math performance looks differently for students with high and low WM (Ramirez et al., 2013).

Future Research

One benefits of the mAMAS is its compatibility with the AMAS, the widely used adult MA scale, and future research may consider a closer inspection of how child MA scores compare to adult scores. It would also be beneficial for future research to seek out samples of students with higher and lower WM and MA, given the evidence that the relation between MA and math performance differs in these subgroups. Researchers interested in further exploring how WM may mediate the relation between MA and math performance may consider controlling for lower level math skills and other cognitive and language variables, as well as observing these variables with the temporal stipulations necessary to make stronger claims about the directionality of the mediation effect (Wu & Zumbo, 2009). In addition, researchers may wish to choose curriculum mastery measures or report card grades, which may be more ecologically valid methods of measuring classroom mathematics achievement. Doing so would also reduce the amount of additional math testing that potentially math anxious students would have to participate in, allowing researchers to seek out students with high MA while avoiding the ethical implications of knowingly causing these students anxiety through participation in standardized math tests. Collecting report card data would also allow researchers to measure MA early in a school year and then follow a cohort of students throughout a school year or across grade levels without investing the additional resources required to test students on normative mathematics measures at multiple timepoints.

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Appendix A

Letter of Consent for Parents

Determining the Contributions of Executive Functioning to Mathematics Task Performance
Principal Investigator: Dr. Rachel Weber, Department of Educational Psychology and Special Education, UBC Phone: XXX–XXX–XXXX, Email: xxxxx@xxxxx **Co-Investigators:** Marley Morton, Department of Educational Psychology and Special Education, UBC Master of Arts in School Psychology Student Phone: XXX–XXX–XXXX, Email: xxxxx@xxxxx Meagan Murphy, Department of Educational Psychology and Special Education, UBC Master of Arts in School Psychology Student Phone: XXX–XXX–XXXX, Email: xxxxx@xxxxx

Please read the following letter carefully. If after reading the letter, you would like to take part in the study, please sign the signature page and return it in this envelope to your child's school. Keep this document for your own records. This letter is a request for your consent to take part in the study we are completing. The title of the study is "Determining the Contributions of Executive Functioning to Mathematics Task Performance".

Why am I doing this project?

Your child is being invited to take part in this research study because your child is a student in Grades 3-6. We want to learn more about how executive functioning (skills that allow individuals to plan, organize and complete tasks), math anxiety, and motivation contribute to children's performance on math tasks such as simple arithmetic, multi-step calculation, and word problem solving. There is still much to learn about how executive functioning, math anxiety, and motivation contribute to different math tasks. By learning more, we hope to improve instructional strategies and support in the classroom for children with math difficulties.

What happens if you agree to take part in this study?

If you agree to take part in the study:

- You will agree to your child completing tests of executive functioning, math anxiety, motivation, and math performance. Altogether, your child's participation will take approximately one and a half hours and will be conducted at school during school hours.
- You will agree to complete a brief questionnaire about your child's executive functioning, and your child's demographic (e.g., age, gender, etc.) information. These two measures will take approximate 20 minutes to complete. The demographic questionnaire is sent home with this letter of consent, and the executive functioning questionnaire will be sent home once you agree to participate.
- We are looking for child participants who have average intelligence, therefore, each participant will complete an intelligence screener. If it is found that the child participant

does not receive a score falling in the average range on the screener, they will not be eligible to participate, but will still receive a small gift. If this occurs, you will be contacted by the principal investigator and informed of the results, which may lead to a psychoeducational evaluation recommendation. All information collected will remain confidential from the school.
- Your participation in this research project is entirely voluntary and you may refuse or withdraw from the study at any time.

What are the risks and benefits if you take part in this study?

- We do not expect you or your child to experience any risks from being in this study.
- Your child's participation (or their decision not to participate) will not impact their child's receipt of any services at school.
- While there are no direct benefits to you or your child participating, you will be contributing to the knowledge related to executive functioning, math anxiety, motivation, and mathematics.

How will your identity be protected?

- This study is being conducted as part of a thesis for the co-investigators Marley Morton and Meagan Murphy. As such, the results of this study will be made a public document.
- However **no individual information will be reported and no person taking part will be identified by name** in any reports about the study.
- The only people who will have access to the information you give are the researchers working on this project.
- Hard copies of this questionnaire will be kept in a locked filing cabinet in Dr. Weber's research lab at UBC. Data collected will be stored on a password-protected computer with encrypted files.

How will I share what I learn?

- The results of this study will be reported in two graduate theses and may also be published in journal articles and books.
- Once the findings are published as a graduate thesis and/or a journal article, the investigators can provide the parents of the participant with the results of the study.
- If you would like to receive results of the study please provide your preferred method of contact below.

Email ______________________________ Mailing Address ______________________________

How will you be compensated?

- We will not pay you for the time you take to be in this study. However your child will receive a small gift for participating, regardless if you withdraw early.

Who can you contact if you want more information about the study?

- If you have any questions or desire further information with respect to this study, you may contact Marley Morton or Meagan Murphy at the email or phone number at the top of this page.

Who can you contact if you have concerns about the study?

- If you have any concerns or complaints about your rights as a research participant and/or your experiences while participating in this study, contact the Research Participant Complaint Line in the UBC Office of Research Ethics at 604-822-8598 or if long distance e-mail RSIL@ors.ubc.ca or call toll free 1-877-822-8598.

Participant Consent

- Taking part in this study is entirely up to you. You have the right to refuse to participate in this study. If you decide to take part, you may choose to pull your child out of the study at any time without giving a reason, and your child will still receive compensation.

Your signature below indicates that you consent to having your child participate in this research project. When you sign below it also means that you have a copy (pages 1-3) of this consent form for your own records.

If you consent to having your child participate in this research study, please complete and return the attached demographic questionnaire along with this signed consent form.

____

Parent/Guardian Signature Date

____

Printed Name of Parent/Guardian signing above

____

Child's Name

Appendix B

Letter of Assent for Students

Consent to Participate in a Research Study

Title: Determining the Contributions of Executive Functioning to Mathematics Task Performance

Principal Investigator:

Dr. Rachel Weber, Department of Educational Psychology and Special Education, UBC
Phone: XXX–XXX–XXXX, Email: xxxxx@xxxxx

Co-Investigators:

Marley Morton, Department of Educational Psychology and Special Education, UBC
Master of Arts in School Psychology Student
Phone: XXX–XXX–XXXX, Email: xxxxx@xxxxx

Meagan Murphy, Department of Educational Psychology and Special Education, UBC
Master of Arts in School Psychology Student
Phone: XXX–XXX–XXXX, Email: xxxxx@xxxxx

What is the purpose of this study?

- You are being invited to take part in this research study because you are a student in Grades 3-6.
- We want to learn more about how people's thinking skills help or make it harder for them when doing math work (e.g., addition and subtraction, and word problems).
- This study is happening so the co-investigators Marley Morton and Meagan Murphy can complete their school program.

What happens if you agree to take part in this study?

If you agree to take part in the study:

- You will agree to complete thinking tests, questionnaires and math activities. Your participation will take approximately one hour and a half.
- You will be asked to complete a test that measures your thinking abilities, all children have to complete this test. But, if you obtain a score on this test that is below or above average, you will not need to complete the rest of the activities (questionnaires and math activities). You will still receive your gift for participating.
- Your participation in this research project is completely up to you, and you may decide to stop participating from the study at any time.

What are the risks and benefits if you take part in this study?

- We do not expect you to experience anything bad from being in this study.
- While there are no benefits to you for helping us, you will be helping the researchers better understand executive functioning and mathematics.

How will your information be private?

- Your name will not be on any of your tests. Instead, you will be given a "code number", and this number will be on your documents.
- All documents will be locked in a filing cabinet. Your name will not be in any of the papers that get written.
- All information will be on a password protected computer.

How will you be compensated?

- For participating you will receive a small gift, even if you stop participating and do not complete everything.

Participation

- Taking part in this study is entirely up to you. You have the right stop participating at any time and you will still receive a small gift. Your signature below indicates that you agree to participate in this research project

____

Child's Name

____

Child's Signature (optional)

Appendix C

Demographic Questionnaire

Child Name: ____________________________________

What is your child's birthdate (day/month/year)? ____________________________________

Child's Gender: ____________

What is the highest level of education/grade **you** completed? ___________________________

Your relationship to child (e.g., mother, father): __________________________

Where was your child born (country)? ____

What is your child's ethnicity (circle one letter)?

a. Aboriginal origins (e.g., First Nations, Inuit, Metis)
b. East Asian origins (e.g., Chinese, Japanese, Korean)
c. Eastern and Southern European origins (e.g., Polish, Russian, Ukranian, Italian, Greek, Spanish)
d. Northern and Western European origins (e.g., British, Scottish, German, Swedish, Danish, Norwegian, Dutch)
e. South Asian origins (e.g., East Indian, Punjabi, Pakistani)
f. Southeast Asian origins (e.g., Filipino, Thai, Vietnamese)
g. Other (please list): ____

Does your child have any developmental delays or learning or behavioural problems that have been identified by a professional (please check one)? ________ Yes ________ No

If Yes, please describe: ____

____

Has your child been diagnosed with any of the following (please check):

___ Autism Spectrum Disorder

___ Learning Disability / Specific Learning Disorder, circle: reading, writing, and/or math

___ Attention Deficit Hyperactivity Disorder

___ Speech Language Impairment

___ Developmental Coordination Disorder

Other, please specify: ______________________

Has your child received or participated in any of the following special health, educational, or community services (please check one for each item)?

	Yes	No	Don't Know
1. Speech and Language			
2. Supported Child Development Program (SCD)			
3. Learning Resource Support			
4. Special Education			
5. Private Tutoring Services			
6. Other (if yes, please describe)			

Please describe the reason for any of the services listed above:

1. Speech and Language	
2. Supported Child Development Program (SCD)	
3. Learning Resource Support	
4. Special Education	
5. Private Tutoring Services	
6. Other (please describe)	

Appendix D

Simple Arithmetic Probe

9 - 2	1 x 10	3 + 3	6 - 1	9 - 5	6 - 5
4 + 3	2 + 6	10 - 6	9 - 6	7 - 2	1 x 5
3 x 8	4 x 4	10 - 9	10 - 4	5 - 2	3 x 9
8 - 3	3 - 1	4 - 1	2 + 7	54 ÷ 6	9 + 4
9 - 4	10 + 10	7 - 6	35 ÷ 5	8 - 6	56 ÷ 8
9 - 5	1 + 8	1 + 5	36 ÷ 9	14 ÷ 2	4 x 3
6 - 2	10 + 6	4 ÷ 2	8 x 6	28 ÷ 7	32 ÷ 8
8 x 1	4 x 1	7 x 3	7 - 6	7 + 10	8 - 7
8 ÷ 1	49 ÷ 7	10 + 8	9 + 3	2 + 9	8 x 2
27 ÷ 9	64 ÷ 8	9 x 7	64 ÷ 8	24 ÷ 6	8 + 7

9 x 4	10 ÷ 1	1 x 8	2 x 8	3 x 9	9 + 3
6 + 8	4 x 8	8 + 4	5 + 1	7 + 7	3 + 3
9 ÷ 3	3 ÷ 1	9 - 2	6 - 5	10 - 9	3 x 3
7 - 5	24 ÷ 4	8 x 3	5 ÷ 1	3 x 3	9 + 1
4 + 5	18 ÷ 3	8 - 1	7 x 8	28 ÷ 7	7 + 3
21 ÷ 7	3 ÷ 3	14 ÷ 7	40 ÷ 10	3 + 5	5 x 6
10 + 7	4 - 2	4 x 7	35 ÷ 7	4 + 8	6 ÷ 3
7 + 7	9 + 5	3 x 10	7 x 7	5 - 2	10 + 2
7 - 5	9 - 2	5 x 3	8 x 2	60 ÷ 10	9 - 5
30 ÷ 3	4 ÷ 2	5 x 4	6 - 1	3 - 1	9 - 3

Appendix E

Adapted Modified Abbreviated Math Anxiety Scale (mAMAS)

Adapted from Carey and colleagues (2017)

Please give each sentence a score in terms of how nervous or worried you would feel during each situation. Use the scale on the right side and circle the number which you think best describes how you feel.

	Low Worry	Some Worry	Moderate Worry	Quite a Bit of Worry	High Worry
1. Having to complete a worksheet by yourself.	1	2	3	4	5
2. Thinking about a math test the day before you take it.	1	2	3	4	5
3. Watching the teacher work out a math problem on the board.	1	2	3	4	5
4. Taking a math test.	1	2	3	4	5
5. Being given math homework with lots of difficult questions that you have to hand in the next day.	1	2	3	4	5
6. Listening to the teacher talk for a long time in math.	1	2	3	4	5
7. Listening to another child in your class explain a math problem.	1	2	3	4	5
8. Finding out you are going to have a surprise math quiz when you start your math lesson.	1	2	3	4	5
9. Starting a new topic in math.	1	2	3	4	5