The Role of Numerical Processing and Working Memory Capacity on the Relationship Between Math Anxiety and Math Performance

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THE ROLE OF NUMERICAL PROCESSING AND WORKING MEMORY CAPACITY ON THE RELATIONSHIP BETWEEN MATH ANXIETY AND MATH PERFORMANCE

A Thesis
Presented to the
Faculty of
California State University,
San Bernardino

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts
in
Psychological Science

by
Pilar Olid
March 2020
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Approved by:

Hideya Koshino, Committee Chair, Psychology
Robert Ricco, Committee Member
John Clapper, Committee Member
ABSTRACT

Math anxiety refers to a negative emotional response to math-related stimuli. Studies have found a negative correlation between math anxiety and math performance—as math anxiety increases, math performance decreases. According to Attentional Control Theory (Eysenck et al., 2007), anxiety impairs executive functions via depletion of working memory (WM) resources. Therefore, math anxiety affects math performance by consuming WM resources. Additionally, poor math performance is attributed to poor numerical processing (NP), which is the ability to estimate quantities. Recent research suggested that math anxiety affects arithmetic indirectly through working memory capacity (WMC) and NP, and that math anxiety affects numeracy—ratios, fractions, and proportional reasoning—indirectly through WMC (Skagerlund, Ostergren, Vastjall, & Traff, 2019). The present study aimed to further investigate these findings. We investigated the moderating effects of WMC and NP on the relationship between math anxiety and math performance (arithmetic and numeracy). We used the magnitude comparison task (i.e., numerical distance, ND) and the parity judgement task (i.e., compatibility effect) to measure NP. Additionally, we investigated whether the relationship between math anxiety and arithmetic might be mediated by WMC and NP (as measured by ND). We found that WMC and NP do not moderate the relationship between math anxiety and math performance, but that WMC and ND do mediate this relationship. We also showed that WMC and ND are negatively correlated. As WMC increase, ND
decreases (i.e., better numerical magnitude representation). Furthermore, WMC was found to fully mediate the relationship between math anxiety and arithmetic. These results suggest that WMC may play a greater role in arithmetic than NP.

Keywords: Math anxiety, working memory capacity, numerical processing, arithmetic, numeracy, math performance
ACKNOWLEDGEMENTS

My deep gratitude goes first to my advisor Dr. Hideya Koshino, who expertly guided me throughout my graduate education. This was a long journey with twists and turns, and without Dr. Koshino’s enthusiasm and patience this work would not have been possible. I have learned and continue to learn a lot from him.

I warmly thank Dr. Robert Ricco for his continuous support, and for always being available and willing to help. His considerate guidance has played an integral part in the completion of this thesis.

I also thank Dr. John Clapper for taking an interest in my research. His insightful feedback and intriguing questions helped improve my work.

I am also grateful to Dr. Jason Reimer for giving me my first position as a researcher assistant. Without that experience I wouldn’t have made it this far.

Also, I thank all the participants that took part in this study and that enabled this research to be possible. Not everyone wants to sit in a dark room to do math.

A special thanks also goes to my parents for their unconditional support. It is their hard work and determination to succeed that inspires me to do the same.

Finally, I thank the many friends and family members that have cheered me on and were happy to lend an ear during this long journey. Thank you!
DEDICATION

I dedicate my work to my niece, Jocelyn. Her joy, her energy, and her kindness remind me that the work that we do now, is not for us, but for the generations to come.

I extend my dedication to everyone that sees the value in education and that does not let age, gender, physical, mental, or economic circumstance be a deterrent. I dedicate this work to you, the hard working, knowledge-seeking student. Never give up, never lose focus, and always look ahead.
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CHAPTER ONE:
INTRODUCTION

Math anxiety refers to a negative emotional experience with math-related stimuli (e.g., Hembree, 1990; Ashcraft, 2002; Maloney & Beilock, 2012; Dowker, Sarkar, & Looi, 2016; Ramirez, Shaw, & Maloney, 2018). Individuals with math anxiety tend to avoid careers that have a high demand on math abilities, avoid math classes beyond degree requirements, and receive low scores in math courses (e.g., Ashcraft, 2002; Ashcraft, & Moore, 2009; Suarez-Pellicioni, Nunez-Pena, & Colome, 2016). Additionally, among college students, those enrolled in math for elementary teachers experienced the highest level of math related anxiety (Hembree, 1990). This is alarming since early math experiences have a major influence in the development of math anxiety (e.g., Beilock, Gunderson, Ramirez, & Levine, 2010; Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015). Ashcraft and Moore (2009) reported that up to 17% of the population experience math anxiety. The 2012 Organization for Economic Co-operation and Development (OECD) report found that 32% of 15-year-olds reported feeling anxious towards mathematics (OECD, 2013). Furthermore, the report revealed that across the globe there is a negative relationship between math anxiety and math performance, as math anxiety increases, math performance decreases (OECD, 2013). Given this worrisome relationship, it merits further investigation.
In particular, it is important to study the underlying mechanisms that may form part of this relationship.
Numerical Processing

Research in mathematical cognition indicates that humans have an innate core ability to process quantities (e.g., Feigenson, Dehaene, & Spelke, 2004; Izard, Sann, Spelke, & Streri, 2009; LeFevre, 2016; Henik, Gliksmann, Kallai, & Leibovich, 2017). This innate core numerical ability is split into two core systems of numerical processing (NP). The first system is called subitizing, and it refers to the automatic ability to detect the number of items in a small set without counting (e.g., Piazza, 2010). Individuals can quickly, accurately, and confidently name the quantity of a collection of objects up to 4, but are unable to do so when 5 or more are presented (e.g., Gilmore, Gobel, & Inglis, 2018). Children can subitize up to 3 items at age 7 but increase to 4 when they reach adulthood (Starkey & Cooper, 1995).

The second core system is the approximate number system (ANS). This system refers to the ability to automatically approximate the number of items in a large set, also without counting (e.g., Odic & Starr, 2018). However, it is harder to distinguish displays that are closer in numerosity—the number of items presented—than displays that are further apart in numerosity (Odic, & Starr, 2018). This ability might be innate. For example, Izard, Sann, Spelke, & Streri (2009) familiarized newborns (i.e., 49 hours of age) with a sequence of auditory syllables (4, 6, 8, 12, or 18) and then presented them with a visual array of the
same (congruent) or different (incongruent) number of geometric shapes. The results showed that newborns stared at the congruent trials more than at the incongruent trials when their numerical value followed a 1:3 ratio. In other words, they can distinguish between 4 vs 12 and 6 vs 18 quantities, but not between smaller quantity differences such as 4 vs 8. The ratio changes to 1:2 in 7-month-olds (Wolfgang, 2006). In adults, the ability to discriminate between quantities improves to a ratio of 7:8 (lazrd et al., 2009; Piazza, 2010). It is from these two core systems that symbolic numerical representations emerge, that is, the ability to actually count and represent items via some modality (i.e., fingers, Arabic digits, Roman numerals, number words, verbal representation).

**Internal Mental Number Line**

Just as there is an innate core numerical ability, there is also an internal mental number line on which these quantities are represented. The ANS is believed to be involved in the internal representation of these quantities (e.g., Feigenson et al., 2004). Just as the ANS is not exact, the internal mental representation of numerical values is also not exact and often yields an overlap between numbers (e.g., Gilmore et al., 2018; Feigenson et al., 2004). A larger overlap in mental activation means that there is more uncertainty in the mental representation of those numbers. There are two possible representations of the mental number line, a linear model and a logarithmic model (see Figure 1). In the linear model, numbers are equally spaced apart, but the standard deviation (SD) associated with each number increases as the value of the number increases.
(i.e., the standard deviation for the number 10 is larger than the standard deviation for the number 1). In this model, smaller valued numbers will yield more precise representation than larger valued numbers (i.e., 1 yields more precise representation than 5 and 10). In the logarithmic model, as the value of the numbers gets larger, the spacing between numbers on the mental number line gets closer, but the SD remains the same across all numbers. In this model, all numbers yield the same mental activation, but there is more uncertainty in the numerical representation of a number as its value gets larger because of the overlap between the numerical representations. For example, 5 and 10 have more overlap than 1 and 5.

Figure 1. Models of the Mental Number Line Representation. Note: (a) Linear Model, and (b) Logarithmic Model. Reprinted with permission from Feigenson, Dehaene, and Spelke (2004).
Numerical Processing Measures

NP is commonly measured using the magnitude comparison task and the parity judgement task (e.g., Dehaene, Bossini, & Giraux, 1993; Odic, & Starr, 2018). Both of these show evidence for the existence of the internal mental number line (e.g., Schneider, Grabner, & Paetsch, 2009). The magnitude comparison task involves comparing two quantities to determine which is larger. This task can be done using non-digits (i.e., non-symbolic numerical magnitudes) or digits (i.e., symbolic numerical magnitudes). In the first case, participants compare, for example, two clusters of dots and judge which of the two clusters has more dots. In the second case, participants compare two digits and judge which is larger. The quantities to be compared can be presented simultaneously or sequentially, and can be used with the less mathematically skilled, like preschool children (Izard et al., 2009), and the more mathematically advanced, like college students. In another version, a single digit can be compared to a target value. For example, participants can be asked to judge whether or not the digits 1-4 and 6-9 are greater than or less than 5. In the magnitude comparison task, numbers whose numerical distance is larger (e.g., 1 vs. 8) yield a shorter reaction time compared to numbers whose numerical distance is smaller (e.g., 4 vs. 5); this phenomenon is known as the numerical distance effect (NDE; Moyer & Landover, 1967). The NDE occurs because there is an overlap in the mental representation of the quantities—it is harder to distinguish numbers that are closer to each other than numbers that are further apart. A large NDE indicates a
less precise numerical magnitude representation (George, Hoffmann, & Schiltz, 2016).

In the parity judgement task, a response is made on whether a presented digit is odd or even. Using this task, Dehaene, Bossini, and Giroux (1993) discovered that smaller valued numbers are responded to faster with the left-hand side, and larger valued numbers are responded to faster with the right-hand side. For example, suppose participants are presented with the single digit 1-9, and are asked to press a key with the left hand if the digit is odd and a key with the right hand if the digit is even. In this case, participants respond faster to odd numbers 1 and 3 than to 7 and 9, and to even numbers 6 and 8 than to 2 and 4. Similar results are observed when participants are asked to respond to even numbers with the left hand and odd numbers with the right hand (e.g., even numbers 2 and 4 and odd numbers 7 and 9 yield faster reaction times than even numbers 6 and 8 and odd numbers 1 and 3; Dehaene et al., 1993). This phenomenon became known as the spatial-numerical association of response codes (SNARC) effect, and it calculated by subtracting the reaction times of the left-hand response from the right-hand response for each digit. A strong SNARC effect is indicated by a strong negative relationship (i.e., negative slope) between the digits and the aforementioned reaction time difference. The spatial location of the digits corresponds with a left-to-right oriented internal mental number line (e.g., Nuerk, Wood, & Willmes, 2005). A strong/weak SNARC effect would indicate a weak/strong internal numerical representation (Georges et al., 2016).
In other words, a strong SNARC effect indicates a poor internal mental number line representation, and a weak SNARC effect is indicative of a good internal mental number line representation. The SNARC effect, although reversed, has also been observed in Iranian participants who write from right to left (Dehaene et al., 1993; Gevers & Lammertyn, 2005). This suggests that the direction of the SNARC effect is dependent on the writing direction of the study population.

Numerical Processing and Math Performance

NP skills are associated with math performance (Merkley & Ansari, 2016; Schneider et al., 2017). In a study of five-and six-year-old children, Kroesbergen, Luit, Lieshout, Loosbroek, and De Rijt (2009) found that subitizing abilities explained 22% of the variance in the development of counting skills. Halberda, Mazzocco, and Feigenson (2008) found that individual differences in acuity (e.g., better estimation) in the ANS were related to individual differences in math achievement. Specifically, sharpness (accuracy) in the ANS in ninth grade was retrospectively predictive of math performance from Kindergarten to sixth grade. Gobel, Watson, Lervag, and Hulme (2014) conducted an 11-month longitudinal study of 6-year-olds to determine the effect of the ANS and knowledge of Arabic numbers on math competence. They found that knowledge of Arabic numerals was a stronger predictor of arithmetic skills (i.e., addition, subtraction, multiplication, and division) than the ANS. The literature also indicates that knowledge about numerical symbols mediates the relationship between informal and formal math education (Merkley & Ansari, 2016; Purpura, Baroody, &
Lorigan, 2013). Schneider, et al., (2017) conducted a meta-analysis of 45 articles (age groups consisted of children, adolescents, and adults) and found that the symbolic numerical magnitude task has a stronger relationship with mathematical competence than the non-symbolic numerical magnitude task. They reasoned that this is due to most assessments of math competence utilizing Arabic numerals. Thus, knowledge of symbolic numbers appears to form a foundation for more advanced NP, which might explain why knowledge of symbolic numbers has been found to have a strong association to math performance.

The relationship between NP and math performance is not unique to the underage population. Sasanguie, Lyons, Smedt, and Reynvoet (2017) conducted a study with adult participants (mean age 20.43) to explore the relationship between knowledge of symbolic number and arithmetic skills. They used the digit version of the magnitude comparison task to measure NP, and the Tempo Test Arithmetic (TTA) to obtain an arithmetic score. The TTA requires participants to solve as many arithmetic problems as possible in one minute. They found a significant direct correlation between digit comparison performance and arithmetic score. Additionally, they found that digit order (i.e., ability to judge if a pair of digits are in the correct order) mediated the effect of the digit comparison task on arithmetic skills. Using the parity judgement task, Hoffmann, Mussolin, Martin, and Schiltz (2014) found that among college students, differences in math proficiency yield differences in the SNARC effect. A weak SNARC effect was found among the arithmetic skilled group, and a strong SNARC effect was found
among the less math proficient group. This suggest that individuals with a good internal mental number line representation (weak SNARC effect) are more arithmetically skilled. However, Cipora and Nuerk (2013) did a similar study, also in the adult population, and did not find a significant relationship between the SNARC effect and arithmetic skills.
CHAPTER THREE:
WORKING MEMORY

Working Memory Capacity

WM refers to the cognitive system that allows for information to be held in mind while performing some complex tasks such as comprehension, reasoning, and learning (e.g., Baddeley, 2010). This is different from short-term memory, which only holds small amounts of information for a brief period of time. WM is made up of three-component: the phonological loop for short-term storage of verbal information; the visuospatial sketchpad for short-term storage of visual and spatial information; and the central executive, which coordinates attentional resources for the manipulation of information temporarily stored in the first two systems (e.g., Baddeley & Hitch, 1994). In order to perform a task such as mental arithmetic, information needs to be temporarily stored and manipulated in working memory (WM; e.g., Gilmore et al., 2018; Peng, Namkung, Barnes, & Sun, 2015; Raghubar, Barnes, & Hecht, 2010). In fact, a metanalysis of 110 studies found that WM and mathematics have a significant moderate correlation of $r = 0.35$ (Peng et al., 2015). Mathematical problems require the use of WM, in particular when multiple steps and or a strategy is needed to obtain a solution (Ashcraft & Krause, 2007). For example, multiplying $25 \times 3$ may require not only keeping the multiplicand 25 and the multiplier 3 in mind, but also requires mentally holding the product of the individual digits (i.e., $3 \times 5 = 15$ and $3 \times 2 = 6$) before adding the 1 from 15 to 6 to arrive at 75. Rosen and Engle (1997) further
stated that individual differences in the number of items that can be maintained in WM, that is, working memory capacity (WMC), accounts for differences in cognitive performance. They found that individuals high on WMC (HWMC) can maintain attention to relevant information and tasks, while individuals low on WMC (LWMC) cannot. Furthermore, LWMC individuals show poor performance compared to HWMC individuals due to internal or external factors that lead to intrusive thoughts, and that compete with available cognitive resources for task execution (e.g., Engle, 2002; Engle, 2018).

**Measures of Working Memory Capacity**

WMC can be measured using WM span tasks. These tasks involve processing one component while subsequently having to remember another component (i.e., a dual-task). The typically used WM span tasks are the reading span task, the operation span task, and the symmetry span task (Figure 1). For example, in the reading span task (Daneman & Carpenter, 1980), participants are asked to verify a sentence and remember a word that follows that sentence. This sentence-word pairing makes up one set. Usually, participants are presented with 2 to 6 sets and are then asked to recall the words. The number of correctly recalled words determines their WMC. In the operation span task (Turner & Engle, 1989), participants need to mentally solve a mathematical expression such as \( \frac{8}{2} - 1 = ? \), and then determine if the follow up number is the answer to the problem. This is followed by a memory item. In the symmetry span task, the problem is replaced by a symmetrical or non-symmetrical figure, which
require a symmetry judgement, and the to be remembered item is replaced by
the spatial location of a red square. These dual-tasks can be administered
independently or together to provide a general measure of WMC (e.g., Oswald,
McAbee, Redick, & Hambrick, 2015).

**Working Memory Capacity and Math Performance**

Individual differences in WMC have also revealed individual differences in
math performance. Lee and Bull (2016) used a dual-task similar to the reading
span task to measure WMC in children whose age ranged from 6- to 15-years-
old. They found that WMC in Kindergarten predicted math growth in 1st to 9th
grade, with the strongest correlation in Grades 1 and 2. Similar results were
found by Dulaney, Vasilyeva, and O'Dwyer (2015) in a measure of children’s
verbal short-term memory capacity. They found that children with higher verbal
short-term memory capacity at 54 months of age showed greater math
performance than children with lower short-term memory capacity, and that this
difference was still evident in fifth grade. Using the operation span task, Wang
and Shah (2014) measured the WMC of 3rd and 4th graders and assessed their
performance on addition problems where 1, 2, or 3 numbers needed to be
carried over to perform the sum. They found that children with HWMC performed
better on all carry over problems compared to children with LWMC.
CHAPTER FOUR:
MATH ANXIETY

Defining Math Anxiety

As stated before, math anxiety is a feeling of tension that interferes with numerical manipulation and mathematical problem solving (e.g., Ashcraft, & Faust, 1994). Although math anxiety is related to general anxiety and other forms of anxiety, it is its own separate construct (Dowker et al., 2016; Suarez-Pellicioni et al., 2016). Hembree (1990) found that math anxiety is correlated to general anxiety by \( r = .35 \). General anxiety is composed of state anxiety, which is a temporary emotional feeling that varies in its intensity and duration, and trait anxiety, which is characterized by a continuous and persistent negative emotional feeling (Gros, Antony, Simms, & McCabe, 2007). Both are brought about by threatening internal or external stimuli that lead to cognitive and behavioral defense mechanisms (Eysenck, Derakshan, Santos, & Calvo, 2007; Gros et al., 2007). Although math anxiety is distinct from general anxiety, it is believed to be a trait-level anxiety since the negative feeling towards mathematics persist (Ramirez, Shaw, et al., 2018). Math anxiety is also different from test anxiety and statistics anxiety. Test anxiety, unlike math anxiety and statistics anxiety, is not subject specific and is experienced in situations when the individual feels that his or her knowledge is being evaluated (Liew, Lench, Kao, Veh, & Kwok, 2014). Math anxiety and test anxiety share 37% of the variance and are correlated by \( r = .52 \), which suggest that the two are not interchangeable.
Statistics anxiety, which is specific to situations that involve statistical tasks, is highly related to math anxiety, $r = .85$, but Paechter, Macher, Martskvishvili, Wimmer, and Papousek (2017) concluded that math anxiety actually predicts statistics anxiety.

Measures of Math Anxiety

There are several measures of math anxiety. These instruments measure attitudes towards mathematics in everyday life (e.g., calculating percentages at a grocery store) and in academic situations (e.g., reading a math textbook, or taking a math exam). They also measure emotions: anxious, afraid, nervous, and confident (Ma, 1999). One of the most popularly used instrument is the Mathematics Anxiety Rating Scale (MARS) developed by Richardson and Suinn in 1972. The MARS is a 98-item measure scaled on a 5-point Likert scale (1-not at all anxious to 5-very much anxious) that contains items such as “adding two three-digit numbers while someone looks over your shoulder” (Richardson, & Suinn, 1972, p. 2). The test has a test-retest reliability of $r = .85$ and is correlated to math performance by $r = -.64$. A meta-analysis found that the MARS was the most often used measure of math anxiety in papers from 1975 to 1999 (Ma, 1999). In 1982, Plake and Parker revised the MARS to a 24-item measure, Mathematics Anxiety Rating Scale-Revised (MARS-R), that correlated with the original instrument ($r = .97$) and showed strong reliability ($r = .98$). The scale was further shortened by Hopko, Mahadevan, Bare, and Hunt (2003) and called the Abbreviated Math Anxiety Scale, or simply, AMAS. The new version contains 9-
items and has a \( r = .85 \) on test-retest reliability and shows strong convergent validity with MARS-R \( (r = .85) \).

**Development of Math Anxiety**

It is unclear how math anxiety develops, but there are several contributing factors. Math anxiety has been found in children as young as first and second grade (Ramirez, Gunderson, Levine, & Beilock, 2012), but is more evident around adolescence (Dowker et al., 2016). Some attribute math anxiety to genetics while others attribute it to environmental influences. Wang, Hart, et al. (2014) conducted a study with 514 twins and found that genetics accounted for 40% of the variance in explaining math anxiety. Others, like Dowker, Sarkar, and Looi (2016), suggest that math anxiety is unlikely to be rooted in a math specific genetic factor and that it is more likely to emerge as a result of general anxiety and negative math experiences.

Parents’ own math anxiety may influence its development in children. Maloney, Ramirez, Gunderson, Levine, and Beilock (2015) conducted a study where they measured parent’s and children’s level of math anxiety and asked the parents about how often they helped their children with their math homework. They found that high math anxious parents who also help their children with their math homework transferred their anxiety. Maloney et al. (2015) argued that it is the parent’s negative attitudes towards mathematics and not their math competence that influence children’s development of math anxiety.
Teachers’ own math anxiety and pedagogical methods may also influence the development of math anxiety. Ramirez, Hooper, Kersting, Ferguson, and Yeager (2018) found that teacher’s math anxiety was correlated with poor math achievement in adolescent children. Furthermore, this was mediated by the student’s perception of whether or not they thought their teacher wanted them to succeed. Beilock, Gunderson, Ramirez, and Levine (2010) measured elementary school female teachers’ math anxiety, children’s math achievement, as well as children’s gender beliefs. Children’s gender beliefs were based on whether they drew a boy or a girl in response to two gender-neutral stories about a child that was either good at math or reading. If the female children drew a boy for the story about the child that is good at math, then this was taken as evidence that they endorsed the math stereotype that men are better at math than women. Beilock et al. (2010) found that the higher the female teacher’s math anxiety, the worse the female children performed on the test of achievement and that this was mediated by the female children’s gender beliefs.

As children age, not only do they become exposed to negative attitudes towards mathematics, but the course content gets harder. The increase in cognitive demand due to more abstract mathematical concepts and more complex arithmetic along with the pressure to do well may lead to feelings of anxiety (Dowker et al., 2016). Additionally, students’ personal fear of being evaluated negatively may lead to avoidance behavior (e.g., avoiding homework or studying), and as a result lead to poor math test scores (Liew et al., 2014).
Cultural differences may also influence the development of math anxiety. Cultures in which there is a high demand to perform well like in Asian countries, such as China, South Korea and Japan, may trigger high anxiety, while countries that may be more relaxed, like Switzerland, do not trigger anxiety (Dowker et al., 2016; Foley et al., 2017).

What Comes First, Math Anxiety or Poor Math Performance?

The question arises whether math anxiety leads to poor math performance, or poor math performance leads to math anxiety. The Debilitating Anxiety Model, also referred to as the Disruption Account, claims that math anxiety leads to poor math performance (e.g., Carey, Hill, Devine, & Szucs, 2016; Ramirez, Shaw, et al., 2018). The support for this account stems from research that shows that individuals with math anxiety avoid experiences where math skills can be improved, such behavior includes enrolling in fewer math courses or selecting careers that have less emphasis on math (e.g., Ashcraft & Krause, 2007; Hembree, 1990). Math anxiety also generates negative intrusive thoughts which leave less room for mathematical processing (Ashcraft & Krause, 2007; Moran, 2016). The intrusive ruminations that co-occur while trying to solve a math problem take up WM resources, which leave less room to actually solve the math problem. Ashcraft and Krause (2007) also found that problems that require more processing, like carry over from multi-step arithmetic which heavily loads WM, are performed more rapidly and less accurately by individuals with
high math anxiety. This is presumably because they are using avoidance behavior by attempting to complete the task as rapidly as possible.

The Deficit Theory, also known as the Reduced Competency Account, on the other hand, claims that poor math performance, that is, low math knowledge and skills, leads to math anxiety (e.g., Ashcraft, & Krause, 2007; Carey et al., 2016; Maloney & Beilock, 2012; Ramirez, Shaw, et al., 2018). As a result of these reduced math abilities, individuals with math anxiety avoid engaging in math activities (e.g., math course, math homework) that further affects their math performance (Hembree, 1990). Additionally, as students move up in grade school and the curriculum becomes more demanding, their anxiety increases. Thus, students develop negative attitudes towards mathematics (Mata, Monteiro, & Peixoto, 2012), which further exacerbates their avoidance behavior.

Since there is strong evidence for both claims, the Reciprocal Theory suggests that the relationship between math anxiety and math performance is bidirectional (Carey et al., 2016; Ramirez, Shaw, et al., 2018). The explanation is that math anxiety and math performance work on a cycle: poor math performance leads to math anxiety, and anxiety leads to poor math performance. However, this cycle does not explain why some people that experience high math anxiety perform well in mathematics, as seen in Asian countries (Mata et al., 2012; Carey et al., 2016; Georges et al., 2016).

Ramirez, Shaw, and Maloney (2018) suggest an alternative, the Interpretation Account, which argues that math anxiety is a result of how the
individual interprets their math experiences. In 1990, Meece, Wigfield, and Eccles conducted a study to investigate whether math performance and perceived math abilities are precursors to the development of math anxiety. They asked 7th and 9th graders about their perceived math abilities, the importance they attribute to math, and how they expect to do in the following academic year, and compared this information to their math grades. Meece et al. (1990) found that students’ own perception of their performance was more predictive of math anxiety development than math grades. Along these same findings, Wang, Lukowski, et al. (2015) did a study involving children and early adolescents found that math motivation (e.g., the value the individual places on math abilities) moderated the effects of math anxiety on math performance. In fact, they found that for those high in math motivation, the relationship between math anxiety and math performance was an inverted U-shape, while for those with low math motivation the relationship was linear in the negative direction. Thus, the high math motivation group benefited from moderate levels of math anxiety. On the other hand, for the low math motivation group, math anxiety hindered their math performance. This alternative approach helps explain how some students with high levels of math anxiety also perform well in mathematics.

**Math Anxiety and Math Performance**

Studies that investigate the relationship between math anxiety and math performance consistently find that they are negatively correlated (e.g., Foley et al., 2017; Hembree, 1990; Ma, 1999). The Programme for International
Assessment (PISA) showed that as the level of math anxiety increases, the degree of math performance decreases ($r = -.56$ and $r^2 = .31$; OECD, 2013). In fact, Foley et al. (2017) showed that for every one-unit increase in math anxiety on the PISA math-anxiety scale, there was a 29-point drop in a given student’s math score. Ma (1999) conducted a meta-analysis of 26 studies and found this correlation to be $r = -.27$ among the children and teenage population. The relationship is even higher among college students, $r = -.31$ (Ashcraft & Moore, 2009). Additionally, individuals with high math anxiety perform poorly on math tasks compared to individuals with low math anxiety (Ashcraft & Faust, 1994). Ashcraft and Faust (1994) divided participants into three groups: low math anxiety (LMA), middle math anxiety (MMA), and high math anxiety (HMA). Each group had to verify arithmetic problems (i.e., $14 + 25 = 49$). Results showed that the LMA group made less errors and was faster at solving the mental arithmetic problems compared to the MMA and HMA groups. Furthermore, the HMA group made more errors than the LMA and MMA groups. This suggest that HMA leads to poor math performance.

**Math Anxiety and Numerical Processing**

Maloney, Ansari, and Fugelsang (2011) proposed that differences in math anxiety in undergraduate students stem from differences in numerical processing. The researchers administered two version of the magnitude comparison tasks: the version that requires identifying if a number is larger or smaller than the target number 5; and the version that requires comparing two
simultaneously presented single digits. They also measured math anxiety using the AMAS. The results of the study showed that in both version of the magnitude comparison task, the HMA group performed worse than the LMA group. They concluded that these differences are due to the HMA group having a less precise mental representation of numerical magnitudes. Georges, Hoffmann, and Schiltz (2016) conducted a study with university students and found similar results using both the magnitude comparison task and the parity judgment task. The HMA group showed stronger (or larger) NDE and stronger SNARC effect than the LMA group. Recall, a large NDE and a strong SNARC effect means weaker numerical processing. Additionally, their correlation analysis revealed that both the NDE and the SNARC effect were negatively correlated with math anxiety: as math anxiety increased, the SNARC effect became stronger (i.e., more negative slope), and the NDE became larger. Furthermore, they also measured arithmetic skills and found that individuals that yield a strong SNARC effect showed weaker arithmetic performance. In other words, poor numerical processing skills are associated with poor math performance. Maloney, Risko, Ansari, and Fugelsang (2010) also found numerical processing to be correlated with math anxiety using a non-symbolic magnitude task. The task required undergraduate students to report on the number of squares presented on a computer screen (set size 1-9). The results showed no difference in performance in the subitizing range (1-4 squares) between the LMA and HMA groups, but there was a difference in the counting range (i.e., ANS range, 5-9 items). The HMA group took longer than the
LMA group to report the number of square pass set size 4. On the other hand, Braham and Libertus (2018) did not find acuity in ANS in the undergraduate student population to be correlated with math anxiety. They used a non-symbolic magnitude task as opposed to a symbolic (or digit) magnitude comparison task. When math performance was taken into account, however, they found a significant three-way interaction. The HMA group showed differences in math performance on applied word problems depending on low or high acuity in ANS (i.e., numerical processing). For the HMA group, those with low numerical processing skills scored lower on applied word problems compared to those with high numerical processing skills. For the LMA group, there was no difference in applied word problem performance among low and high numerical processing skills. These studies suggest that high math anxious individuals have difficulties with basic NP.

Math Anxiety and Working Memory Capacity

It is believed that math anxiety affects math performance via intrusive thoughts that load WM resources and, thus, interfere with attentional control. This is in line with Eysenck, Derakshan, Santos, and Calvo’s (2007; also, Eysenck, & Calvo, 1992) Attentional Control Theory (ACT). According to ACT, anxiety consumes mental resources, resulting in reduction of available capacity for executive functions, including the ability to ignore (or inhibit the response to) internal or external threat-related stimuli that interferes with task execution. They distinguish between processing effectiveness and efficiency. In typical cognitive
tasks, effectiveness is measured with performance accuracy, and efficiency is measured with accuracy divided by response times, which measures the amount of effort put into the task. Effectiveness might be unaffected if subjects put effort into the task; whereas performance efficiency is affected. Therefore, if intrusive thoughts interfere with task performance, then efficiency scores are worse than effectiveness scores. Furthermore, the ACT posits that the inhibition function is affected more by threat-related distractors than by neutral distractors. Shi and Liu (2016) found results that are consistent with the ACT. They modified the reading span task to include math-related sentences and neutral sentences. The letters to be remembered were of set size 3, 4 or 5. They also measured math anxiety and split participants into two groups: HMA and LMA. The HMA group did worse in the math-related sentences condition for set sizes 4 and 5 than the LMA group. There were no differences in the neutral sentences condition. These findings suggest that WMC was impaired by intrusive thoughts brought about by the math context in the HMA group. In fact, Moran (2016) did a meta-analysis consisting of 177 studies and found that anxiety, in general, was related to poor performance due to deficits in WMC, again, suggesting that anxiety interferes with task-related processes. Ashcraft and Krause (2007) suggested that math anxiety acts as a dual task in HMA individuals by taking up WM resources.

Furthermore, differences in WMC have been found to moderate the effect of anxiety on performance. Owens, Stevenson, Hadwin, and Norgate (2014) measured participants’ (mean age = 13.4) general trait anxiety, WMC, and
performance. Owens et al. (2014) measured anxiety using Spielberger’s 20-item measure, STAIC (Spielberger, Edwards, Lushene, Montouri, & Platzek, 1973), which consist of statements such as, “Unimportant thoughts run through my mind and bother me” that are rated on a 3-point Likert-type scale. WMC was measured using a forward and backward digit recall test, and a forward and backward spatial span test. Participants were then divided into three groups: HWMC, MWMC, and LWMC. Cognitive tests included a measure of spatial reasoning (i.e., Raven’s standard progressive matrices, SPM; Raven, Raven, & Court, 1998) and a math computation test (i.e., wide range achievement test, WRAT 4; Wilkinson, & Robertson, 2006). In the math computation test, participants were given 15 minutes to solve as many math problems as possible that increase in level of difficulty. For the LWMC group, the relationship between anxiety and cognitive test performance was negative, $\beta = -.35$, as anxiety scores increased, performance on the cognitive tests decreased. The relationship was positive for the HWMC group, $\beta = .49$, as anxiety scores increased, so did performance on the cognitive tests; and there was no significant relationship for the MWMC group. In other words, differences in performance among individuals with high levels of anxiety might be attributed to differences in WMC. Owens et al. suggest that individuals that do well on cognitive test despite high levels of anxiety might be due to “increased motivation to avoid negative evaluation” (p. 98). Ramirez, Gunderson, Levine, and Beilock (2012) found the opposite effect in children. They used a forward and backward digit span task to measure WMC, the
Woodcock-Johnson II Applied Problems subtest (i.e., math-related word problems; Woodcock, McGrew, & Mather, 2001) to measure math performance, and the Children Math Anxiety Questionnaire (CMAQ; Suinn et al., 1988) to measure math anxiety. The results of their study showed that for the HWMC group, as math anxiety increased, math achievement decreased, and that for the LWMC group, as math anxiety increased, math performance remained stable. Ramirez et al. (2012) also found that math performance in those with HWMC was particularly impaired by problems that required more complex solving strategies, which heavily load WM. They posit that individuals with HWMC are affected more by math anxiety than those with LWMC because worry combined with high task demand depletes their available cognitive resources.

**Math Anxiety, Working Memory, Numerical Processing, and Math Performance**

To the best of our knowledge, Skagerlund, Ostergren, Vastfjall, and Traff (2019) are the first to jointly investigate the effects of WMC and NP on the relationship between math anxiety and math performance in the adult population. Skagerlund et al. (2019) measured math anxiety using the Mathematics Anxiety Scale-UK (MAS-UK), which consists of 23 items rated on a 5-point Likert Scale (Hunt, Clarck-Clarck, & Sheffield, 2011). WMC was measured using the digit span subtest of the Wechsler Adult Intelligence Scale IV (Wechsler, 2008). In these tests, participants recited a series of digits either forward, backward, or in order with up to 16 digits in each category. To measure NP, they used a 1-digit (e.g., digits in the range 1-9) and a 2-digit comparison tasks. In both tasks,
participants compared two simultaneously presented digits whose numerical distance varied by 1 unit or 4-5 units. Two aspects of math performance were measured: numeracy and arithmetic. Numeracy refers to “the basic understanding of the number line, time, measurement, and estimation, as well as higher level concepts such as fractions, proportions, percentages, and probabilities” (Skagerlund et al., 2019, p. 2). Numeracy was measured using the Berlin Numeracy Test (Cokely, Galesic, Schulz, & Ghazal, 2012; see methods section for details), and arithmetic was measured by having participants complete as many addition, subtraction, multiplication, and division problems as possible in 120 seconds—each problem increasing in difficulty. Skagerlund et al. analyzed the data using path analyses, and found that the path through WMC and the path through NP, together accounted for 56% of the variance of the effect of math anxiety on arithmetic skills, and that the path through WMC, only, explained 26% of the variance of math anxiety on numeracy skills. In other words, math anxiety has an indirect effect on arithmetic via WMC and NP, but only an indirect effect on numeracy via WMC. Additionally, they found a direct effect of math anxiety on arithmetic. Skagerlund et al. concluded that the path through which math anxiety affects math performance depends on the aspect of math that is being tested; WM and NP play a role in the effect that math anxiety has on arithmetic, but only WM plays a role in the effect that math anxiety has on numeracy (see Figure 2 for their conceptual model). However, they tested the
effects of WMC and NP separately, and didn’t include the model that combines the effects of WMC and NP.

![Conceptual Model](image)

Figure 2. Skagerlund, Ostergren, Vastfjall, and Traff’s (2019) Conceptual Model. *Note:* Path between math anxiety (MA) and arithmetic/numeracy through working memory (WM) and numerical processing (NP).

**Summary**

Math anxiety is a world-wide problem that affects a lot of people and whose underlying mechanisms are little understood. It is clear, however, that
math anxiety affects math performance (e.g., Foley et al., 2017). At the basic level, math performance involves NP (e.g., LeFevre, 2016). There are two basic core NP systems, subitizing and the ANS, from which symbolic numerical representations emerge (i.e., digits). Symbolic numbers form the foundation for higher mathematics such as arithmetic and numeracy (e.g., Feigenson et al., 2004). Research finds that poor skills in NP relates to poor performance in arithmetic (e.g., Hoffmann et al., 2014; Sasaguie et al., 2017). Furthermore, individual differences in NP skills are associated with individual differences in math word problems when math anxiety is taken into account (Maloney, Ansari, & Fugelsang, 2011). Those low in NP skills and high on math anxiety perform worse than those high on NP and high on math anxiety (Braham & Libertus, 2018). These studies suggest that NP combined with math anxiety affects math performance. This is consistent with the Deficit Theory which posits that poor NP skills lead to math anxiety.

It is also clear that solving a mathematical problem requires the use of WM (e.g., Peng et al., 2015). Not only do the rules involving math operations and their relationship with numbers need to be stored in long term memory, but also math calculation often requires managing and manipulating several digits at the same time (e.g., Ashcraft & Krause, 2007). Additionally, individual differences in WMC affects math performance (e.g., Lee & Bull 2016; Moran, 2016). Research involving children found that those high on WMC performed better in mental arithmetic problems compared to those low on WMC (Wang & Shah, 2014). This
same relationship pattern has been found even when anxiety is taken into account. Owens et al. (2014) found that for individuals high on WMC, as level of anxiety increases so do performance scores on cognitive tests (including a measure of math skills). On the other hand, when measuring math anxiety, Ramirez et al. (2012) found that for those high on WMC, as math anxiety increases, math performance decreases. Research speculates that math anxiety affects the resources available for WM, which then affects math performance (e.g., Ashcraft, & Krause, 2007; Eysenck et al., 2007). This reasoning is consistent with the Debilitation Anxiety Model, which suggests that math anxiety affects math performance due to intrusive thoughts brought on by the anxiety that tax WM resources. The research suggest that math anxiety affects math performance and math performance affects math anxiety, thus, their relationship appears to be bidirectional (e.g., Ramirez, Shaw, et al., 2018).

Some studies have further investigated the effects of NP and WMC on the relationship between math anxiety and math performance. Skagerlund et al. (2019) found that math anxiety affects arithmetic performance through NP and WMC, and numeracy performance through NP. However, they did not test an interaction between NP and WMC. Regardless of the number of underlying mechanisms that affect the relationship between math anxiety and mathematical constructs, it is clear that math anxiety negatively affects math performance.
CHAPTER FIVE:
RATIONAL AND HYPOTHESES

Given the studies discussed here, we have reason to believe that the relationship between math anxiety and math performance might be moderated through NP and WMC. In the present study, math anxiety is compared to general anxiety, and math performance is assessed through arithmetic and numeracy skills. Two tasks, the magnitude comparison task and the parity judgement task, were used to determine NP skills, which is then split into three groups (i.e., low, median, and high). WMC is measured with three span tasks then split into three groups (i.e., LWMC, MWMC, HWMC). We use the three groups to evaluate the moderation effect of NP and WMC on math anxiety and math performance.

Skagerlund et al. (2019) investigated the effects of NP and WMC, independently, on the relationship between math anxiety and math performance. However, they did not test an interaction effect between NP and WMC on the relationship between math anxiety and math performance. Therefore, the present study is designed to add to our understanding of how math anxiety affects math performance by investigating whether this relationship is moderated via NP and WMC. We hypothesized the following relationships (see Figure 3):

1. The relationship between math anxiety and math performance is expected to be negative for the low NP group and positive for the high NP group: as math anxiety increases, math performance decreases/increases, respectively.
2. The relationship between math anxiety and math performance will be negative for the low WMC group and positive for the high WMC group: as math anxiety increases, math performance decreases/increases, respectively.

Figure 3. Hypothesis 1 and 2. Note: Expected interaction between math anxiety and numerical processing (NP) on math performance. The same pattern applies for working memory capacity (WMC).

Method

Participants

One hundred and fifty (136 women, $M = 25.4$ years, age range: 18-72 years) students were recruited to participate for course credit. Participants had normal to corrected normal eye vision and were fluent in English. All participants
signed the informed consent form that was approved by the Institutional Review Board. Seventeen participants were excluded due to missing data (N = 6) or had below chance accuracy rates (N = 11). This resulted in 133 participants (121 women, $M = 25.3$ years, age range: 18-72 years).

Overall Design

Regression analyses were used to investigate the relationship between math anxiety and math performance using NP and WMC as moderating variables. Math anxiety, based on scores on the AMAS, was used as the independent variable and math performance, based on the scores on the Berlin Numeracy Test (BNT) and the equation verification task (EVT), were used as the dependent variables (BNT scores, and EVT scores, and combined BNT and EVT scores). For hypothesis 1, NP scores were divided into three groups (33% each) based on results from the parity judgement task and the magnitude comparison task. For hypothesis 2, WMC, based on WM span tasks (i.e., operation, reading, and symmetry), was divided into three groups (33% each).

Materials

All tasks were administered on a PC computer with E-Prime 3.0 (Psychology Software Tools, Pittsburgh, PA). All stimuli were presented against a gray background and were viewed from a distance of 60 cm.
Working Memory Span Tasks

WMC was measured using three working memory span tasks (i.e., operation span task, reading span task, and symmetry span task) following Oswald, McAbee, Redick, and Hambrick (2015), and they are shown in Figure 4.

Operation Span Task. At the beginning of each trial, participants were presented with a math problem (e.g., $8 \div 2 - 1 = ?$). They were then asked to mentally solve the problem as quickly and as accurately as possible. Once they had solved the problem, they needed to click on the mouse to continue. On the next screen, an answer appeared. Participants needed to click on “True” if the answer was correct or “False” if the answer was incorrect. Next, a single letter out of twelve possible options (e.g., F, H, J, K, L, N, P, Q, R, S, T, and Y) was presented. Participants needed to remember the letter for later recall. The number of to be remembered letters varied by trial. At the end of each trial, participants selected the letters in the order that they were presented by clicking in the box next to the twelve letters arranged in a $4 \times 3$ matrix. Participants had the option to select a blank space for any letter they had forgotten. Participants could also “Clear” their response. Once they were done, they clicked on “Exit” for the next trial to begin. Each trial consisted of a set size 4 to 6 (see Oswald et al., 2015 for detail). The maximum number of letters correctly recalled in a trial determined their memory span. Participants had three practice blocks, one for letters only (2 trials), one for equations only (15 trials), and one for equations plus
letters (8 trials). The main task consisted of 6 blocks of 8 trials. The set size per block was randomized.

**Reading Span Task.** The structure of the reading span task was the same as in the operation span task, except that instead of an arithmetic problem, participants were be presented with a sentence such as “During the week of final spaghetti, I felt like I was losing my mind [emphasize added].” In this case, participants needed to determine if the sentence made sense. As soon as they made this judgement they needed to click on the mouse, and on the next screen, they needed to select “true” or “false.” This was followed by the to be remembered letter.

**Symmetry Span Task.** At the start of each trial, participants were presented with a figure generated by black and white squares in an 8 × 8 matrix. Participants needed to determine if the shape made by the black squares represented a symmetrical figure along the vertical axis. Once they made their judgement, they clicked the mouse and on the next screen they indicated if the figure was symmetrical by clicking on “Yes” or “No.” Then participants were presented with a 4 × 4 matrix of white squares where some squares were shaded in red. Participants needed to remember the locations of the red squares. Each trial ranged from set size 4 to 6. At the end of each trial, participants were shown a 4 X 4 grid, and they were told to select the squares that were shaded in red in the order in which they appeared. The maximum number of correctly recalled red squares, in the correct order and location, determined memory span.
Figure 4. Trial Sequence for the Operation, Reading, and Symmetry Span Tasks.

Math Performance Tasks

Two aspects of math performance were measured: numeracy and arithmetic. To measure numeracy, participants completed the Berlin Numeracy Test (BNT) and to measure arithmetic, participants completed the equation verification task (EVT).

Berlin Numeracy Test (BNT). The BNT, created by Cokely, Galesic, Schulz, and Ghazal (2012), assesses numeracy skills. The test consists of questions such as, “Imagine we are throwing a five-sided die 50 times. On average, out of these 50 throws how many times would this five-sided die show an odd number (1, 3, or 5)?”. Participants completed the four-item multiple-
choice version for the educated population. Cokely et al. (2012) recommend the adaptive four-item version, where only 2-3 questions of the possible 4 are asked. However, we followed Skagerlund et al.’s (2019) procedure by administering all 4 questions and using the total score as the numeracy index. Additionally, the test was completed on the computer, and one question appeared at a time along with the 4 multiple choice options. Participants used the computer mouse to mark their selection. Two and a half minutes were allowed for each question. (See Appendix A)

Equation Verification Task (EVT). This task required participants to verify the correctness of a set of equations adopted from Cipora and Nuerk (2013). The equations came from the following categories: (a) two-digit by one-digit/two-digit number division (e.g., 63/9 = 7), and (b) order of operations and parentheses (e.g., 2 + 7 × 3 = 27 and (12 + 13) × 2 = 60). At the beginning of each trial, participants were presented with a central fixation point for 500 msec. Then an equation appeared which replaced the central fixation point. Participants responded as quickly and as accurately as possible to whether or not the equation was correct by pressing the left-hand key “X” if the equation was correct, or the right-hand key “N” if the equation was incorrect. The allotted response time ended at 20 sec for each question. A blank screen was presented for 1500 msec between each trial. There were 2 blocks, each consisting of 20 equations where half were correct, and half were incorrect. There was a practice
block with 4 trials. No feedback was provided during the main session, only during the practice trials.

**Numerical Processing Tasks**

Numerical processing was measured using two tasks: parity judgment task (PJT) and magnitude comparison task (MCT).

**Parity Judgement Task (PJT).** Participants were presented with a single digit, from 1-9, except 5, and judged if it was odd or even. Each trial started with a central fixation point presented for 500 msec. Then the digit appeared on the center of the screen above the fixation cross for 2000 msec or until a response was made. For one group, participants pressed the left-hand key “X” if the digit was odd, and the right-hand key “N” if the digit was even. For the other group of the participants the key press was reversed. Participants responded as quickly and accurately as possible. There were 8 blocks with 48 trials each, along with practice trials (2 blocks of 24 trials each). During the main task, feedback was only provided if no response was detected. Either the feedback, or a blank screen, was presented for 1,000 msec until the start of the next trial.

**Magnitude Comparison Task (MCT).** In this version of the magnitude comparison task, participants were presented with two single-digit numbers and determined which was the largest. The task began with a central fixation point (500 msec) followed by two digits side by side. Participants pressed the left-hand side key, “X,” if the left digit was larger than the right digit, or the right-hand key, “N,” if the right digit was larger than the left digit. The digits remained on the
screen until a response was made or for 1500 msec. The digits had a distance of 1 unit or 4 units (e.g., 1 vs 2, or 5 vs 9), and appeared in chronological or reverse order (e.g., 3 vs 7, or 7 vs 3). This made up a total of 26 combinations.

Participants completed 4 blocks with 26 trials each.

**Anxiety Measures**

Two anxiety measures were administered, one for trait anxiety and the other for math anxiety.

**State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA).** The STICSA, as previously described, consists of 21 items rated on a 4-point Likert scale (1-not at all, 2-a little, 3-moderately, 4-very much so; Gros et al., 2007). Each measure (State and Trait scales) of the STICSA addresses cognitive symptoms (10 items) and somatic symptoms (11 items). We only measure trait anxiety. Each question was presented one at a time until a response was made. Participants used the computer mouse to mark their response on the scale and clicked on the “continue” button to move to the next question. The larger the score, the more anxious the individual. (See Appendix B)

**Abbreviated Math Anxiety Scale (AMAS).** The AMAS questions (Hopko, Mahadevan, Bare, & Hunt, 2003) were presented in the same format as the STICSA. The 5-point Likert-type scale (1-low anxiety to 5-high anxiety) was located below each question. Participants use the computer mouse to mark their response and to then clicked on “continue” to move on to the next question (9
total questions). The larger the score, the more anxious the individual. (See Appendix C)

**Demographic Survey**

The demographic survey included questions about handedness, highest level of math reached, major, learning disabilities, mental illnesses, and head trauma. (See Appendix D)

**Procedure**

The experiment took place in a group format (up to 12 participants at a time) in a dimly light room. After signing the informed consent form, participants were given verbal instructions on the tasks that they would be completing during the session. Participants started with the working memory span tasks. The tasks were completed in the following order: operation span task, reading span task, and symmetry span task. Participants then completed the math performance tasks; the BNT followed by the EVT. Then the NP measures were administered. Participants first completed the PJT and then the MCT. Next, they completed the anxiety measures, STICSA followed by the AMAS; and, finally, the demographic questionnaire. At the end of the experiment participants were debriefed and thanked for their participation. The entire session took approximately one hour and thirty minutes to complete.
CHAPTER SIX:

RESULTS

Data Screening and Analyses

Outliers were screened by running a simple linear regression analysis with continuous variables: Data that exceeded Mahalanobis, Cook’s, and Leverage distance scores were excluded from the analysis: Mahalanobis = 22.46; Cook’s = 0.032; and Leverage = 0.105. Nine participants were excluded, which resulted in a total of 124 participants (113 women, $M = 25.5$ years, $SD = 7.96$, age range: 18-72 years). Assumptions for additivity and normality were inspected and met.

Abbreviated Math Anxiety Scale

Total response on the 9 Abbreviated Math Anxiety Scale (AMAS) questions were used to determine participant’s math anxiety score ($M = 23.9$, $SD = 7.34$, range: 9-41 points).

State-Trait Inventory for Cognitive and Somatic Anxiety

Participant’s total response was used as their State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA) score for trait anxiety ($M = 39.5$, $SD = 10.93$, range: 21-77 points). For three participants, a mean imputation was inserted on one question each due to missing data.

Math Performance Measures

Accuracy scores for both the equation verification task (EVT) and the Berlin Numeracy Test (BNT) were transformed using the logit function to correct for ceiling and floor effects: EVT ($M = 1.7$, $SD = 0.92$) and BNT ($M = -2.1$, $SD =$
2.21). We also calculated efficiency coefficient scores for the EVT. Efficiency coefficient scores were calculated for each participant using the following formula: accuracy rates divided by reaction times (RTs), multiplied by 1,000. The mean efficiency coefficient score was 0.4, SD = 0.26. Additionally, EVT and BNT logit accuracy scores were combined to form a general measure of math performance (MP; M = 0.5, SD = 0.12).

**Numerical Processing Measures**

Numerical processing scores were determined using the magnitude comparison task and the parity judgement task. These scores were kept separate.

**Magnitude Comparison Task (MCT).** Following Skagerlund et al. (2019), the mean reaction times (RTs) on the two conditions (numerical distance of 1 and 4) were combined to obtain participants’ numerical distance (ND) score. Mean RT of numerical distance 1 (\(M = 628.9, SD = 96.65\)) was significantly longer than mean RT of numerical distance 4 (\(M = 552.7, SD = 67.89\)), \(t(123) = 19.59, p < .001\), suggesting that it was easier to distinguish between two digits when they are farther apart (numerical distance effect, NDE). The mean RT for the combined numerical distances was 590.8, \(SD = 80.65\). ND was used in the data analyses instead of the difference between distance 1 and 4 (i.e., NDE) because the mean RT retains information regarding the speed of numerical processing, which might be lost when we use the distance effect. The shorter the RTs, the better the numerical processing. Participants were divided into three groups
based on their mean ND: top 33%, middle 33%, and bottom 33% (see to Table 1 for descriptive statistics).

Table 1. Descriptive Statistics for Numerical Distance Groups.

<table>
<thead>
<tr>
<th></th>
<th>ND</th>
<th>AMAS</th>
<th>MP</th>
<th>EVT</th>
<th>BNT</th>
<th>WMC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HND</strong> (N = 42)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>680.7</td>
<td>23.9</td>
<td>0.5</td>
<td>0.4</td>
<td>-2.7</td>
<td>0.5</td>
</tr>
<tr>
<td>SD</td>
<td>46.96</td>
<td>7.21</td>
<td>0.11</td>
<td>0.24</td>
<td>2.18</td>
<td>0.75</td>
</tr>
<tr>
<td><strong>MND</strong> (N = 41)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>587.1</td>
<td>23.7</td>
<td>0.5</td>
<td>0.4</td>
<td>-1.8</td>
<td>0.6</td>
</tr>
<tr>
<td>SD</td>
<td>16.30</td>
<td>7.06</td>
<td>0.12</td>
<td>0.20</td>
<td>2.34</td>
<td>0.86</td>
</tr>
<tr>
<td><strong>LND</strong> (N = 41)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>502.3</td>
<td>24.2</td>
<td>0.6</td>
<td>0.6</td>
<td>-1.9</td>
<td>1.1</td>
</tr>
<tr>
<td>SD</td>
<td>30.95</td>
<td>7.91</td>
<td>0.13</td>
<td>0.30</td>
<td>2.03</td>
<td>0.86</td>
</tr>
</tbody>
</table>

*Note.* ND = numerical distance based on mean reaction time on the magnitude comparison task. HND = high ND. MND = middle ND. LND = low ND. AMAS = Abbreviated Math Anxiety Scale. MP = math performance based on the average logit scores on the equation verification task and Berlin Numeracy Test. EVT = equation verification task logit efficiency scores. BNT = Berlin Numeracy Test logit accuracy scores. WMC = working memory capacity logit accuracy scores.

Parity Judgement Task (PJT). Accuracy scores and reaction times were separated into compatible and incompatible conditions. Trials in which hand response matched digit location on the internal mental number line (e.g., left-hand response and digit is small [1-4] or right-hand response and digit is large [6-9]) made up the compatible conditions. The incompatible conditions consisted of trials in which hand response did not match digit location on the internal mental number line (e.g., digit is small [1-4] and right-hand response or digit is large [6-9].
and left-hand response). Since we only collected responses from each participant under one condition (i.e., left-hand “odd” and right-hand “even” or left-hand “even” and right-hand “odd”), we computed the compatibility effect (RT for incompatible – RT for compatible conditions). To correct ceiling effect, accuracy scores were re-scaled using a logit transformation. The logit accuracy scores were then used to calculate efficiency coefficient scores for the compatible and incompatible conditions. The mean efficiency coefficient for the compatible condition ($M = 6.8, SD = 1.97$) was significantly higher than the mean efficiency coefficient for the incompatible condition ($M = 6.1, SD = 1.8$), $t(124) = 3.89, p < .001$, suggesting that participants were more efficient in the compatible than in the incompatible conditions. The efficiency scores for the incompatible condition were then subtracted from those for the compatible condition for each participant ($M = 0.7, SD = 2.05$). The difference between compatible and incompatible conditions is called the compatibility effect (CE), which was used for data analyses. Higher efficiency scores mean better performance, which corresponds with better representation of the internal mental number line. Therefore, a high CE means better numerical processing, which relates to a weak SNARC effect. The participants were divided into three groups based on the CE: top 33%, middle 33%, and bottom 33%. See Table 2.
Table 2. Descriptive Statistics for Compatibility Effect Groups.

<table>
<thead>
<tr>
<th></th>
<th>PJT</th>
<th>AMAS</th>
<th>MP</th>
<th>EVT</th>
<th>BNT</th>
<th>WMC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compatible</td>
<td>Incompatible</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCE</td>
<td>ACC</td>
<td>4.6</td>
<td>3.0</td>
<td>610.6</td>
<td>3.0</td>
<td>23.9</td>
</tr>
<tr>
<td>(N = 42)</td>
<td>RT</td>
<td>572.7</td>
<td>610.6</td>
<td></td>
<td>0.61</td>
<td>55.63</td>
</tr>
<tr>
<td></td>
<td>MCE</td>
<td>ACC</td>
<td>3.9</td>
<td>3.7</td>
<td>614.5</td>
<td>0.6</td>
</tr>
<tr>
<td>(N = 41)</td>
<td>RT</td>
<td>602.3</td>
<td>614.5</td>
<td></td>
<td>0.96</td>
<td>73.29</td>
</tr>
<tr>
<td></td>
<td>LCE</td>
<td>ACC</td>
<td>3.3</td>
<td>4.2</td>
<td>613.1</td>
<td>-1.5</td>
</tr>
<tr>
<td>(N = 41)</td>
<td>RT</td>
<td>616.4</td>
<td>613.1</td>
<td></td>
<td>0.82</td>
<td>83.15</td>
</tr>
</tbody>
</table>

Note. PJT = parity judgement task. ACC = logit accuracy scores. RT = reaction time. CE = compatibility effect from efficiency scores on the parity judgement task. HCE = high CE. MCE = middle CE. LCE = low CE. AMAS = Abbreviated Math Anxiety Scale. MP = math performance based on the average logit scores on the equation verification task and the Berlin Numeracy Test. EVT = equation verification task logit efficiency scores. BNT = Berlin Numeracy Test logit accuracy scores. WMC = working memory capacity logit accuracy scores.

Working Memory Capacity Measure

Accuracy rates on the three working memory capacity (WMC) measures were re-scaled using a logit transformation to correct for ceiling effects: operation span (Mean = 1.3, SD = 1.55), reading span (Mean = 1.0, SD = 1.47), and symmetry span (Mean = 0.4, SD = 1.19). Following Oswald et al. (2015), scores from all three tasks were combined for each participant to obtain a composite measure of
WMC ($M = 0.7$, $SD = 0.85$). Participants were then divided into three groups based on their WMC scores: top 33%, middle 33%, and bottom 33%. See Table 3.

Table 3. Descriptive Statistics Based on Working Memory Capacity Groups.

<table>
<thead>
<tr>
<th></th>
<th>WMC</th>
<th>AMAS</th>
<th>MP</th>
<th>EVT</th>
<th>BNT</th>
<th>ND</th>
<th>CE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HWMC</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 42)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>1.7</td>
<td>21.2</td>
<td>0.6</td>
<td>0.5</td>
<td>-1.6</td>
<td>566.5</td>
<td>0.8</td>
</tr>
<tr>
<td>SD</td>
<td>0.49</td>
<td>6.57</td>
<td>0.12</td>
<td>0.27</td>
<td>1.97</td>
<td>79.63</td>
<td>2.27</td>
</tr>
<tr>
<td><strong>MWMC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 41)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.8</td>
<td>24.1</td>
<td>0.5</td>
<td>0.4</td>
<td>-2.2</td>
<td>615.5</td>
<td>0.7</td>
</tr>
<tr>
<td>SD</td>
<td>0.17</td>
<td>6.88</td>
<td>0.11</td>
<td>0.21</td>
<td>2.16</td>
<td>78.12</td>
<td>1.99</td>
</tr>
<tr>
<td><strong>LWMC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 41)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>-0.1</td>
<td>26.1</td>
<td>0.5</td>
<td>0.4</td>
<td>-2.5</td>
<td>588.7</td>
<td>0.6</td>
</tr>
<tr>
<td>SD</td>
<td>0.46</td>
<td>7.77</td>
<td>0.13</td>
<td>0.29</td>
<td>2.41</td>
<td>78.88</td>
<td>1.93</td>
</tr>
</tbody>
</table>

*Note.* WMC = working memory capacity. HWMC = high WMC. MWMC = middle WMC. LWMC = low WMC. AMAS = Abbreviated Math Anxiety Scale. MP = math performance based on the average logit scores on the equation verification task and Berlin Numeracy Test. EVT = equation verification task logit efficiency scores. BNT = Berlin Numeracy Test logit accuracy scores. ND = numerical distance based on mean reaction time on the magnitude comparison task. CE = compatibility effect from efficiency scores on the parity judgement task.
Correlation Analysis

All main variables were submitted to a correlation analysis (see Table 4). The correlation analysis revealed a moderate positive correlation between AMAS and STICSA, \(r = 0.47, r^2 = 0.22, p < .001\). However, STICSA was not correlated with any measures other than AMAS. AMAS is also correlated with WMC (i.e., mean logit accuracy), \(r = -0.24, r^2 = 0.06, p = .006\), and EV (i.e., efficiency on the equation verification task), \(r = -0.20, r^2 = 0.04, p = .024\), but not with BN (i.e., accuracy on the Berlin Numeracy Test), \(r = -0.05, r^2 = 0.003, p = .552\), and MP, \(r = -0.13, r^2 = 0.02, p = .144\). ND (i.e., mean reaction time on the magnitude comparison task) was significantly correlated with WMC, \(r = -0.22, r^2 = 0.05, p = .013\), EV, \(r = -0.32, r^2 = 0.10, p < .001\), BN, \(r = -0.18, r^2 = 0.03, p = .040\), and MP, \(r = -0.21, r^2 = 0.05, p = .017\). CE (i.e., compatibility effect on parity judgment task) was significantly correlated with ND only, \(r = -0.22, r^2 = 0.05, p = .015\). WMC was significantly correlated with EV, \(r = 0.35, r^2 = 0.12, p < .001\), BN, \(r = 0.21, r^2 = 0.05, p = .022\), and MP, \(r = 0.30, r^2 = 0.09, p = .001\).
Table 4. Correlation Matrix.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. AMAS</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>2. STICSA</td>
<td>.474**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. ND</td>
<td>0.018</td>
<td>-0.121</td>
<td>1</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. CE</td>
<td>-0.041</td>
<td>0.126</td>
<td>-0.217*</td>
<td>1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Ospan</td>
<td>-0.202*</td>
<td>0.002</td>
<td>-0.183*</td>
<td>0.031</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Rspan</td>
<td>-0.218*</td>
<td>0.022</td>
<td>-0.215*</td>
<td>-0.047</td>
<td>.418**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>7. Sspan</td>
<td>-0.101</td>
<td>0.080</td>
<td>-0.122</td>
<td>-0.020</td>
<td>.281**</td>
<td>.382**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. WMC</td>
<td>-0.244**</td>
<td>0.014</td>
<td>-0.222*</td>
<td>-0.004</td>
<td>.717**</td>
<td>.756**</td>
<td>.744**</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. EV</td>
<td>-0.202*</td>
<td>0.005</td>
<td>-0.322**</td>
<td>0.119</td>
<td>.226*</td>
<td>.233**</td>
<td>.257**</td>
<td>.348**</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>10. BN</td>
<td>-0.054</td>
<td>0.059</td>
<td>-0.184*</td>
<td>0.061</td>
<td>.205*</td>
<td>0.176</td>
<td>0.059</td>
<td>.205*</td>
<td>0.164</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>11. MP</td>
<td>-0.124</td>
<td>0.048</td>
<td>-0.214*</td>
<td>0.056</td>
<td>.263**</td>
<td>.222*</td>
<td>0.135</td>
<td>.297**</td>
<td>.456**</td>
<td>.931**</td>
<td>1</td>
</tr>
</tbody>
</table>

Note. ** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed). AMAS = Abbreviated Math Anxiety Scale. STICSA = State-Trait Inventory for Cognitive and Somatic Anxiety. ND = average numerical distance reaction time of the magnitude comparison task. CE = logit efficiency coefficient for compatibility effect of the parity judgment task. Ospan = logit accuracy on operation span task. Rspan = logit accuracy on reading span task. Sspan = logit accuracy on symmetry span task. WMC = logit working memory capacity. EV = logit efficiency coefficient scores on equation verification task. BN = logit accuracy on Berlin Numeracy Test. MP = math performance based on the average logit scores on the equation verification task and Berlin Numeracy Test.
Regression Analyses

All regression analyses were performed using the PROCESS Procedure for SPSS Version 3.4 by Andrew F. Hayes (2018). In all analyses, AMAS was used as the independent variable. The main dependent variables were MP (combined average logit accuracy scores on the equation verification task and Berlin Numeracy Test), EV (logit efficiency coefficient scores on the equation verification task), and BN (logit accuracy scores on the Berlin Numeracy Test).

Hypothesis 1: NP on the Relationship Between Math Anxiety and Math Performance

To test the effect of NP on the relationship between math anxiety and math performance, we performed six regression analyses. Since two measures were used for NP (i.e., ND and CE), we ran separate regression analyses for each measure.

Numerical Distance as Moderator. For the magnitude comparison task, we used the mean reaction time for ND (with three levels: HND, MND, LND) as the moderating variable. The HND group had longer RTs in the magnitude comparison task than the LND group. The results of these analyses are shown in Table 5.

Math Performance (MP). The overall model was not significant, $F(5, 118) = 1.65, R^2 = 0.07, p = .151$, and was not improved by entering ND, $F(2, 118) = 0.63, R^2 \text{ change} = 0.01, p = .536$. Performance in the magnitude comparison task did not moderate the relationship between math anxiety and math
performance, which was measured as a combination of the equation verification task and the Berlin Numeracy Test.

Table 5. Regression Models with Numerical Distance as the Moderating Variable.

<table>
<thead>
<tr>
<th></th>
<th>MP</th>
<th>EV</th>
<th>BN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>b</td>
<td>t</td>
<td>b</td>
</tr>
<tr>
<td><strong>Model 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>1.65</td>
<td>5.04***</td>
<td>1.52</td>
</tr>
<tr>
<td>R</td>
<td>0.26</td>
<td>0.42</td>
<td>0.25</td>
</tr>
<tr>
<td>Rs</td>
<td>0.07</td>
<td>0.18</td>
<td>0.06</td>
</tr>
<tr>
<td>AMAS</td>
<td>-0.04+</td>
<td>-1.71</td>
<td>-0.01</td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>0.63</td>
<td>0.14</td>
<td>1.35</td>
</tr>
<tr>
<td>ΔR²</td>
<td>0.01</td>
<td>0.002</td>
<td>0.02</td>
</tr>
<tr>
<td>LND vs MND</td>
<td>0.20</td>
<td>0.74</td>
<td>0.20***</td>
</tr>
<tr>
<td>HND vs MND</td>
<td>-0.40</td>
<td>-1.48</td>
<td>0.001</td>
</tr>
<tr>
<td>LND vs HND</td>
<td>-0.60</td>
<td>-2.23</td>
<td>-0.20***</td>
</tr>
<tr>
<td><strong>Simple Slopes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LND x AMAS</td>
<td>-0.04+</td>
<td>-1.71</td>
<td>-0.01</td>
</tr>
<tr>
<td>MND x AMAS</td>
<td>-0.02</td>
<td>-0.58</td>
<td>-0.01</td>
</tr>
<tr>
<td>HND x AMAS</td>
<td>-0.003</td>
<td>-0.09</td>
<td>-0.01+</td>
</tr>
</tbody>
</table>

*Note.* †p < .10. ***p < .001. ND = numerical distance. MP = math performance. EV = logit efficiency scores on the equation verification task. BN = logit accuracy scores on the Berlin Numeracy Test.

*Arithmetic (EV).* The overall model was significant, F(5, 118) = 5.04, R² = 1.18, p < .001. However, the model was not improved by entering ND, F(2, 118) = 0.17, R² change = 0.002, p = .846. There was a statistically significant difference between LND (M = 0.58) and MND (M = 0.38), b = 0.20, t(118) = 3.77,
$p < .001$, and between LND and HND ($M = 0.38$), $b = -0.20$, $t(118) = -3.77$, $p < .001$. Participants who showed shorter RTs for the magnitude comparison task exhibited better performance in the equation verification task than the other two groups. There was a no significant difference between HND and MND, $b = 0.001$, $t(118) = 0.01$, $p = .989$. To further investigate these relationships, we compare the simple slope effects (see Figure 5). The slope of HND was marginally significant, $b = -0.01$, $t(118) = -1.84$, $p = .069$. The slopes for LND and MND were not significantly different from zero, $b = -0.01$, $t(118) = -1.58$, $p = .116$, and $b = -0.01$, $t(118) = -0.97$, $p = .333$, respectively.
Figure 5. The Moderation Effect of Numerical Processing on the Relationship Between Math Anxiety and Arithmetic. *Note:* Numerical Processing (NP) is based on mean numerical distance reaction time on the magnitude comparison task. LND = low numerical distance. MND = middle numerical distance. HND = high numerical distance. Math anxiety is based on mean centered AMAS scores. Arithmetic is based on logit efficiency coefficient scores on the equation verification task.

Numeracy (BN). The overall model was not significant, $F(5,118) = 1.40$, $R^2 = 0.06$, $p = .189$. The model was also not improved by entering ND, $F(2,118) = 0.40$, $R^2 change = 0.02$, $p = .264$. The numerical distance RT did not moderate the relationship between math anxiety and the Berlin Numeracy Test scores.
Compatibility Effect (CE) as Moderator. For the parity judgement task, we used the CE (i.e., difference between efficiency score for the compatible and incompatible conditions) as the moderating variable with levels: HCE, MCE, LCE. The results of these analyses are shown in Table 6.

Math performance (MP). The overall model that used CE as the moderating variable was not significant, \( F(5,118) = 0.64, R^2 = 0.03, p = .668. \) Entering CE did not improve the model, \( F(2,118) = 0.14, R^2 \text{ change} = 0.002, p = .871. \) The compatibility effect on the parity judgement task did not moderate the relationship between math anxiety and math performance.

Arithmetic (EV). The overall model was not significant, \( F(5,118) = 1.38, R^2 = 0.06, p = .238, \) nor was it improved by entering CE as the moderating variable, \( F(2,118) = 0.86, R^2 \text{ change} = 0.01, p = .428. \) The compatibility effect on the parity judgement task did not moderate the relationship between math anxiety and arithmetic performance on the equation verification task.

Numeracy (BN). The overall model was not significant, \( F(5,118) = 0.49, R^2 = 0.02, p = .782, \) nor was it improved by the moderating variable CE, \( F(2,118) = 0.34, R^2 \text{ change} = 0.01, p = .71. \) The compatibility effect on the parity judgement task did not moderate the relationship between math anxiety and numeracy scores on the Berlin Numeracy Test.
Table 6. Regression Models with Compatibility Effect as the Moderating Variable.

<table>
<thead>
<tr>
<th></th>
<th>MP</th>
<th></th>
<th>EV</th>
<th></th>
<th>BN</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$b$</td>
<td>$t$</td>
<td>$b$</td>
<td>$t$</td>
<td>$b$</td>
</tr>
<tr>
<td><strong>Model 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$F$</td>
<td>0.64</td>
<td></td>
<td></td>
<td>1.38</td>
<td></td>
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</tr>
<tr>
<td>$R$</td>
<td>0.16</td>
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<td></td>
<td>0.23</td>
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<td></td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.03</td>
<td></td>
<td></td>
<td>0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AMAS</td>
<td>-0.03</td>
<td>-1.14</td>
<td>-0.01</td>
<td>-1.34</td>
<td>-0.02</td>
<td>-0.44</td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td></td>
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</tr>
<tr>
<td>$F$</td>
<td>0.14</td>
<td></td>
<td></td>
<td>0.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta R^2$</td>
<td>0.002</td>
<td></td>
<td></td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCE vs MCE</td>
<td>0.18</td>
<td>0.64</td>
<td>-0.02</td>
<td>-0.28</td>
<td>0.16</td>
<td>0.31</td>
</tr>
<tr>
<td>HCE vs MCE</td>
<td>0.29</td>
<td>1.05</td>
<td>0.004</td>
<td>0.07</td>
<td>0.56</td>
<td>1.14</td>
</tr>
<tr>
<td>LCE vs HCE</td>
<td>0.11</td>
<td>0.40</td>
<td>0.02</td>
<td>0.36</td>
<td>0.41</td>
<td>0.82</td>
</tr>
<tr>
<td><strong>Simple Slopes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LCE x AMAS</td>
<td>-0.03</td>
<td>-1.14</td>
<td>-0.002</td>
<td>-0.32</td>
<td>-0.04</td>
<td>-0.90</td>
</tr>
<tr>
<td>MCE x AMAS</td>
<td>-0.03</td>
<td>-0.91</td>
<td>-0.01</td>
<td>-1.34</td>
<td>-0.02</td>
<td>-0.44</td>
</tr>
<tr>
<td>HCE x AMAS</td>
<td>-0.01</td>
<td>-0.47</td>
<td>-0.01*</td>
<td>-2.17</td>
<td>0.01</td>
<td>0.24</td>
</tr>
</tbody>
</table>

*Note.* *p* < .05. CE = compatibility effect. MP = math performance. EV = logit efficiency scores on the equation verification task. BN = logit accuracy scores on the Berlin Numeracy Test.

**Hypothesis 2: WMC on the Relationship Between Math Anxiety and Math Performance**

Three regression analyses were performed to test the moderating effect of WMC on the relationship between math anxiety and math performance. WMC was entered as the moderating variable with three categories: HWMC, MWMC, LWMC. (See Table 7.)

**Math Performance (MP).** The overall model was not significant, $F(5,118) = 1.62$, $p = .159$, $R^2 = 0.06$. The model was not improved by entering WMC,
$F(2, 118) = 1.07$, $R^2_{\text{change}} = 0.02$, $p = .346$. WMC did not moderate the relationship between math anxiety and math performance (composite scores on the equation verification task and the Berlin Numeracy Test).

Table 7. Regression Models with Working Memory Capacity as the Moderating Variable.

<table>
<thead>
<tr>
<th></th>
<th>MP</th>
<th>EV</th>
<th>BN</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Model 1</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$F$</td>
<td>1.62</td>
<td>2.89*</td>
<td>1.01</td>
</tr>
<tr>
<td>$R$</td>
<td>0.25</td>
<td>0.33</td>
<td>0.20</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.06</td>
<td>0.11</td>
<td>0.04</td>
</tr>
<tr>
<td>AMAS</td>
<td>0.003</td>
<td>-0.01</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>0.09</td>
<td>-1.00</td>
<td>0.76</td>
</tr>
<tr>
<td><strong>Model 2</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$F$</td>
<td>1.07</td>
<td>2.08</td>
<td>1.01</td>
</tr>
<tr>
<td>$\Delta R^2$</td>
<td>0.02</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>LWMC vs MWMC</td>
<td>-0.16</td>
<td>-0.57</td>
<td>0.02</td>
</tr>
<tr>
<td>HWMC vs MWMC</td>
<td>0.32</td>
<td>1.08</td>
<td>0.10</td>
</tr>
<tr>
<td>LWMC vs HWMC</td>
<td>0.47</td>
<td>1.63</td>
<td>0.07</td>
</tr>
<tr>
<td><strong>Simple Slopes</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LWMC $\times$ AMAS</td>
<td>-0.0004</td>
<td>-0.02</td>
<td>0.0003</td>
</tr>
<tr>
<td>MWMC $\times$ AMAS</td>
<td>0.003</td>
<td>0.09</td>
<td>-0.01</td>
</tr>
<tr>
<td>HWMC $\times$ AMAS</td>
<td>-0.05</td>
<td>-1.67</td>
<td><strong>-0.02</strong></td>
</tr>
</tbody>
</table>

*Note.* *p* < .05. WMC = working memory capacity. MP = math performance. EV = logit efficiency scores on the equation verification task. BN = logit accuracy scores on the Berlin Numeracy Test.

**Arithmetic (EV).** The overall model was significant, $F(5, 118) = 2.89$, $R^2_2 = 0.11$, $p = .017$. However, the model was not improved by entering WMC, $F(2, 118) = 2.08$, $R^2_{\text{change}} = 0.03$, $p = .130$. The difference between HWMC and LWMC was not significant, $b = 0.07$, $t(118) = 1.25$, $p = .213$, nor was it between
LWMC and MWMC, $b = 0.02$, $t(118) = 0.42$, $p = .672$, and between HWMC and MWMC, $b = 0.10$, $t(118) = 1.65$, $p = .103$. The relationship between math anxiety and arithmetic efficiency (simple slopes) for LWMC and MWMC was not significant, $b = 0.0003$, $t(118) = 0.06$, $p = .951$, and $b = -0.01$, $t(118) = -1.00$, $p = .321$, respectively. However, the simple slope for HWMC was significant, $b = -0.02$, $t(118) = -2.53$, $p = .013$; as the anxiety scores increase, there is a decrease in arithmetic efficiency (see Figure 6). The high WMC group performed the equation verification task better than the other two group when their anxiety is low; however, this difference disappeared when math anxiety is high.
Figure 6. The Moderation Effect of Working Memory Capacity on the Relationship Between Math Anxiety and Arithmetic. Note: Working memory capacity (WMC) is based on the average logit accuracy rates on the operation, reading, and symmetry span tasks. LWMC = low working memory capacity. MWMC = middle working memory capacity. HWMC = high working memory capacity. Math anxiety is based on mean centered AMAS scores. Arithmetic is based on logit efficiency coefficient scores on the equation verification task.

Numeracy (BN). The overall model was not significant, $F(5,118) = 1.01$, $R^2 = 0.04$, $p = .417$. The model was also not improved by entering WMC, $F(2,118) = 1.01$, $R^2$ change = 0.02, $p = .369$. WMC did not moderate the relationship between math anxiety and numeracy scores on the Berlin Numeracy Test.
Mediation Analysis

The results of our moderation analysis did not support our hypotheses; however, our correlation analysis revealed that WMC is correlated with math anxiety, ND, and arithmetic. ND is correlated with WMC and arithmetic, though it is not correlated with math anxiety, (see Table 4). Also, the results of the correlation and the moderation analyses suggest that the parity judgement task might not be a good measure of NP, and that the Berlin Numeracy Test might also not be a good measure of math performance. Therefore, we ran further analyses to test whether WMC and ND mediate the effect of math anxiety on arithmetic.

We ran a serial mediation analysis using PROCESS. In this analysis, we used AMAS (i.e., math anxiety) as the independent variable, EV (i.e., arithmetic) as the dependent variable, and WMC and ND as the mediating variables. Figure 7 shows the direct and indirect effect of AMAS on arithmetic. The standardized regression coefficients for the model are shown in Table 8. The overall model was statistically significant, $R^2 = 0.04$, $F(1,122) = 5.20, p = .024$. The total effect path coefficient was significant, $c = -.20$, $t(122) = -2.28, p = .024$; math anxiety, WMC and ND had an effect on arithmetic. The direct effect path coefficient was not significant, $c' = -.13$, $t(122) = -1.60, p = .112$; math anxiety did not have a direct effect on arithmetic performance. Thus, the mediation model was supported. WMC uniquely explained a significant portion of the relation between math anxiety and arithmetic: standardized bootstrap point estimate $a_1b_1 = -0.06,$
SE = 0.03, 95% CI = -0.136 to -0.011. Thus, the model yields full mediation through WMC. The mediating effect of ND is not significant: standardized bootstrap point estimate $a_2b_2 = 0.01$, $SE = 0.02$, 95% CI = -0.039 to 0.062. There is a significant double mediation by WMC and ND: standardized bootstrap point estimate $a_1a_2b_2 = -0.01$, $SE = 0.01$, 95% CI = -0.040 to -0.001. There is no significant difference between the path that goes through WMC and the path that goes through both WMC and ND, $SE = .031$, 95% CI = -0.122 to 0.001.

Figure 7. Serial Multiple Mediation Model for the Relationship Between Math Anxiety and Arithmetic Proficiency by Working Memory Capacity and Numerical Distance. *Note:* Values are standardized regression coefficients. Working memory capacity (WMC) is based on logit scores. Numerical distance (ND) refers to the mean RT on the magnitude comparison task. Arithmetic refers to efficiency scores on the equation verification task (i.e., EV). *$p < .05$. **$p < .01$
Table 8. Serial Multiple Mediator Model Predicting Arithmetic Proficiency from Math Anxiety Though Working Memory Capacity and Numerical Processing: Standardized Regression Coefficients, Standard Errors, and Summary Information.

<table>
<thead>
<tr>
<th>Antecedent</th>
<th>Coeff.</th>
<th>SE</th>
<th>p</th>
<th>Coeff.</th>
<th>SE</th>
<th>p</th>
<th>Coeff.</th>
<th>SE</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>M₁ (WMC)</td>
<td></td>
<td>M₂ (ND)</td>
<td></td>
<td>Y (Arithmetic)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X (MA)</td>
<td>a₁</td>
<td>-0.244</td>
<td>0.010</td>
<td>&lt; .001</td>
<td>a₂</td>
<td>-0.038</td>
<td>1.003</td>
<td>.678</td>
<td>c’</td>
</tr>
<tr>
<td>M₁ (WMC)</td>
<td></td>
<td></td>
<td></td>
<td>d₁</td>
<td>-0.231</td>
<td>8.771</td>
<td>.013</td>
<td>b₁</td>
<td>0.257</td>
</tr>
<tr>
<td>M₂ (ND)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>b₂</td>
<td>-0.263</td>
<td>0.027</td>
<td>.004</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>iₘ₁</td>
<td>1.408</td>
<td>0.253</td>
<td>.006</td>
<td>iₘ₂</td>
<td>616.923</td>
<td>27.264</td>
<td>&lt; .001</td>
<td>i₅</td>
</tr>
</tbody>
</table>

Note. MA = math anxiety. WMC = working memory capacity. ND = numerical distance. WMC is based on logit scores on the three span tasks (i.e., operation, reading, and symmetry). ND is based on mean numerical distance RT (i.e., ND) on the magnitude comparison task. Arithmetic refers to logit efficiency scores (i.e., EV) on the equation verification task.
CHAPTER SEVEN:

DISCUSSION

The aim of this study was to investigate whether numerical processing (NP) and WMC moderate the relationship between math anxiety and math performance. We also compared the relationship between math anxiety and general anxiety to math performance. For this second part, we found math anxiety to be negatively correlated with arithmetic, which is consistent with the literature (e.g., Hembree, 1990; Ma, 1999; Foley et al., 2017). However, we found no relationship between general trait anxiety and math performance. Also, the correlation between math anxiety and trait anxiety was moderate which is consistent with Hembree’s (1990) study. These findings are consistent with the literature that math anxiety and general anxiety are separate constructs and that math anxiety is negatively correlated with arithmetic.

The first hypothesis investigated the moderating effect of NP measured by numerical distance (ND) and the compatibility effect of the parity judgment task on the relationship between math anxiety and math performance. We predicted a positive correlation for the high NP group (i.e., LND and HCE) and a negative correlation for the low NP group (i.e., HND and LCE). No prediction was made for the middle NP group. These relationships were also individually investigated for arithmetic (EV) and numeracy (BN). The separate models for math performance (average arithmetic and numeracy scores) and for numeracy did not yield
significant results. ND and the CE did not moderate the relationship between math anxiety and math performance. Similarly, the relationship between math anxiety and numeracy was not moderated by ND and the CE. The CE also did not moderate the relationship between math anxiety and arithmetic.

ND also did not moderate the relationship between math anxiety and arithmetic; however, the overall model was significant. In other words, math anxiety was negatively correlated with arithmetic. For all ND groups (i.e., LND, MND, and HND), as math anxiety increased, arithmetic performance decreased (see Figure 5). Thus, contrary to what we predicted, the relationship between math anxiety and arithmetic for the LND group was negative, even though this relationship did not reach statistical significance. Consistent with our hypothesis, however, the relationship between math anxiety and arithmetic for the HND group was negative, albeit marginally significant. The difference between the LND and the MND and HND groups was significant. The effect of ND is smaller for the LND groups (i.e., shorter RT), which indicates a more precise representation of numerical magnitude; ergo, a more precise internal mental number line. Additionally, the LND group performed better on the arithmetic task than the MND and HND groups. In other words, arithmetic performance was better for individuals with good magnitude representation (i.e., LND) and worse for individuals with poor magnitude representation (i.e., HND), even though the effects of anxiety were the same across three groups, arithmetic performance decreased as math anxiety increased.
The second hypothesis investigated the moderating effect of WMC. It was hypothesized that the relationship between math anxiety and math performance would be positive for the HWMC group and negative for the LWMC group. No prediction was made for the MWMC group. These relationships were also separately investigated for arithmetic and numeracy. The hypothesis for math performance and numeracy was not supported. For arithmetic, the overall model was significant, even though WMC does not have a moderating effect. There was no difference between LWMC, MWMC, and HWMC. However, the slope of HWMC was significant, but contrary to our hypothesis, it was in the negative direction (see Figure 6). Thus, for the HWMC group, as math anxiety increased, arithmetic scores decreased. The HWMC group showed better performance in the arithmetic task than the MWMC and LWMC groups for low anxiety; however, this effect disappeared for high math anxiety (see Table 3). For the LWMC group, there was no evident relationship between math anxiety and arithmetic performance. Similar results were observed by Ramirez, Gunderson, Levine, and Beilock (2012) in the children population. They found a negative relationship between math anxiety and math achievement for their HWMC group, and no relationship for their LWMC group. Furthermore, they compared performance on easy (single digit arithmetic) vs hard problems (two-digit arithmetic and simple fraction calculations) and found that performance was impaired for the hard problems for those with high math anxiety and HWMC. In other words, individuals with HWMC are more impaired by math anxiety because they rely
more on WM to solve computationally demanding problems, whereas individuals with LWMC tend to use problem solving shortcuts (Beilock, 2008). Our equation verification task included problems that required more varied solving strategies (i.e., order of operations), which might explain why performance was impaired for our HWMC group as levels of math anxiety increased. Alternatively, the negative direction for our HWMC group could be explained by level of motivation. While we did not measure motivation, Wang, Lukowski, et al. (2015) found that in individuals with low math motivation, the relationship between math anxiety and math performance was negative. Thus, it is possible that our HWMC group was not motivated to do well in the arithmetic task. To encourage good performance, future studies could tell participants that if they perform well, they will be entered into a raffle that will be awarded at the end of the study.

A possible explanation for our non-significant results for numeracy is that the Berlin Numeracy Test (BNT) is meant to measure “statistical numeracy and risk literacy” (Cokely, Galesic, Schulz, & Ghazal, 2012, p. 25). We measured math anxiety, which research suggest is a different construct from statistics anxiety (Paechter et al., 2017). Skagerlund et al. (2019) also used the BNT to measure numeracy and did not find a direct path from math anxiety to numeracy. Although, they did find an indirect path through WM. According to Skagerlund et al., math anxiety is related to numeracy through WM because numeracy requires more abstract thinking, which involves WM to a greater extent than NP. Perhaps the BNT is a better performance measure when studying statistic anxiety than
when studying math anxiety. Another possibility is that Cokely et al. (2012) tested the BNT on a sample that primarily consisted of undergraduate and graduate students. Our participants were undergraduate students, so conceivably the BNT was too difficult for our participants as evident by the floor effect in raw scores. Future research should investigate the relationship between math anxiety and numeracy using a more appropriate numeracy measure.

We also ran a mediation analysis. In this analysis, we tested the mediating effects of WMC and NP (determined by ND) on the relationship between math anxiety and arithmetic. This analysis showed that WMC mediates the relationship between math anxiety and arithmetic. Our findings are consistent with the results of Skagerlund et al. (2019), which showed that math anxiety has an indirect effect on arithmetic through WM. We found that the higher the math anxiety the lower the WMC, and as WMC increases, the better the arithmetic performance scores (see Figure 7). These results are consistent with Eysenck et al.’s (2007) ACT, which states that anxiety consumes mental resources, which in turn, depletes WMC. As math anxiety increases, it generates more intrusive thoughts, which load WM and leave less room for mental arithmetic. In other words, those with HWMC are affected with anxiety more than those with LWMC because individuals with LWMC already showed the floor level performance even with low anxiety, so math anxiety has little effect on their performance. Therefore, reducing math anxiety may help increase math performance for those with high levels of anxiety. Park, Ramirez, and Beilock (2014) showed that writing about
the math related anxiety for 7 minutes before a math task helped increase math performance scores. Writing about the anxiety reduced unwanted thoughts during the math task, which freed WM resources. Therefore, participants had more resources available to perform the math problems. Future research should look into techniques that can help individuals with math anxiety, alleviate their anxiety to boost performance.

Our mediation analysis did not find NP (i.e., ND) alone to mediate the relationship between math anxiety and arithmetic. This is consistent with Douglas and LeFevre’s (2017) research. Similar to our study, they measured math anxiety using the AMAS and NP using the symbolic magnitude comparison task. Additionally, they measured two aspects of arithmetic, calculation fluency in arithmetic (double-digit addition, subtraction and multiplication) and procedural arithmetic (problems that increase in difficulty and included fractions, decimals, and algebra). However, unlike our study, they used arithmetic as the independent variable and math anxiety as the dependent variable. They found that NP does not mediate the relationship between arithmetic and math anxiety. Despite having a similar design to ours and to Douglas and LeFevre, Skagerlund et al. (2019) found an indirect path from math anxiety to arithmetic through NP. They used a different statistical technique (i.e., structural equation model, SEM) and a different measure for math anxiety (i.e., MAS-UK), which might be responsible for this difference in results.
Additionally, we also found that WMC and NP (i.e., ND), together, mediate the relationship between math anxiety and arithmetic. Skagerlund et al. (2019) found that math anxiety indirectly affects arithmetic through WMC and NP, separately. Here, a key difference between Skagerlund et al.’s study and ours is that we performed a serial mediation analysis while they used a SEM that did not investigate the direct link between WMC and NP. Thus, we were able to establish a connection between WMC and NP. We found that as WMC increases, ND decreases (i.e., smaller ND). In other words, higher WMC is related with better numerical magnitude representation. Moreover, we found that as ND increases (i.e., larger ND), arithmetic ability decreases. In addition to the research mentioned in the previous paragraph, Douglas and LeFevre used SEM to show that WMC is related to math anxiety through NP and arithmetic (i.e., calculation fluency and procedural arithmetic). They concluded that individual differences in WMC together with deficits in NP skills accounted for poor arithmetic performance, and that poor arithmetic is associated with higher levels of math anxiety. Additionally, they did a mediation analysis that showed that NP fully mediated the relationship between WMC and calculation fluency, and that NP only partially mediated the relationship between WMC and procedural arithmetic. These results are consistent with our finding, which show that WMC precedes NP in its effect on arithmetic. Additionally, we showed that as math anxiety increases, WMC decreases; then, as WMC increases, ND decreases; and as ND decreases, arithmetic performance increase. These results suggest that lower
math anxiety, together with higher WMC and better NP (i.e., small ND) are associated with better arithmetic skills. Future research should further investigate the relationship between WMC and NP to determine if individual difference in WMC is associated with individual differences in NP and how these relationships might be related to math anxiety and math performance.

Furthermore, our correlation analysis did not find math anxiety to be correlated with NP (i.e., ND), but it did find math anxiety to be negatively correlated with arithmetic. These findings are inconsistent with previous research, which has found math anxiety to be correlated with NP (Maloney et al., 2011; Georges et al., 2016; Braham & Libertus, 2018). However, they are consistent with Ashcraft and Faust (1994), which found that math anxiety affected performance on complex arithmetic problems, but not simple addition and multiplication problems. Moreover, we found a significant negative correlation between ND and arithmetic, which is consistent with the literature (e.g., Merkley & Ansari, 2016; Schneider et al., 2017). In other words, as ND increases (i.e., large ND), there is a decrease in arithmetic performance. Recall, the larger the ND, the less precise the numerical magnitude representation (i.e., poor internal mental number line). Our results show a link between ND and arithmetic, and between math anxiety and arithmetic, but not between math anxiety and ND. Therefore, math anxiety only affects performance in computationally demanding math problems.
The findings from the present study provide support the Debilitating Anxiety Model (or Disruption Account) which posits that math anxiety leads to poor math performance via the weight that it places on WM. In other words, the anxiety brought on by math generates unwanted ruminations that interfere with math related tasks and as a result hinders math performance. Our results also support the Attentional Control Theory (Eysenck et al., 2007), which also postulates that anxiety interferes with WM resources. We see this evident in the mediating effect of WMC on the relationship between math anxiety and arithmetic. As the anxiety increases there are less WM resources available for arithmetic processing, so at low WMC there is poor arithmetic performance.

Taken together, the moderation analyses indicate that NP and WMC do not moderate the relationship between math anxiety and math performance; however, WMC and NP do mediate the relationship between math anxiety and arithmetic. Additionally, the results indicate that WMC is a precursor to the effect of NP on arithmetic. Moreover, WMC alone was found to mediate the relationship between math anxiety and arithmetic. These results suggest that WMC may play a greater role in arithmetic performance than NP. Additionally, we did not find math anxiety to be related to NP. The mediating effect of WMC and NP on the relationship between math anxiety and simple arithmetic should be investigated to provide a comparison and further determine if math anxiety only has an effect on complex arithmetic. To conclude, these findings provide further insight on the
relationship between math anxiety and math performance so that future research can find techniques that can alleviate the effects of math anxiety.
APPENDIX A:
THE BERLIN NUMERACY TEST
(Cokely, Galesic, Schulz, & Ghazal, 2012)
The Berlin Numeracy Test (Multiple choice format)

Instructions: Please answer the questions below. Do not use a calculator but feel free to use the space available for notes (i.e., scratch paper).

1. Imagine we are throwing a five-sided die 50 times. On average, out of these 50 throws how many times would this five-sided die show an odd number (1, 3, or 5)?
   a) 5 out of 50 throws  b) 25 out of 50 throws  c) 30 out of 50 throws  d) None of the above

2. Out of 1,000 people in a small town 500 are members of a choir. Out of these 500 members in the choir 100 are men. Out of the 500 inhabitants that are not in the choir 300 are men. What is the probability that a randomly drawn man is a member of the choir? Please indicate the probability in percent.
   a) 10%  b) 25%  c) 40%  d) None of the above

3. Imagine we are throwing a loaded die (6 sides). The probability that the die shows a 6 is twice as high as the probability of each of the other numbers. On average, out of these 70 throws, about how many times would the die show the number 6?
   a) 20 out of 70 throws  b) 23 out of 70 throws  c) 35 out of 70 throws  d) None of the above

4. In a forest 20% of mushrooms are red, 50% brown and 30% white. A red mushroom is poisonous with a probability of 20%. A mushroom that is not red is poisonous with a probability of 5%. What is the probability that a poisonous mushroom in the forest is red?
   a) 4%  b) 20%  c) 50%  d) None of the above

Scoring = Count total number of correct answers.
Correct answers are: 1 = c; 2 = b; 3 = a; 4 = c
APPENDIX B:

STATE AND TRAIT INVENTORY FOR COGNITIVE AND SOMATIC ANXIETY SURVEY

(Gros, Antony, Simms, & McCabe, 2007)
State and Trait Inventory for Cognitive and Somatic Anxiety (STICSA) Survey

Below is a list of statements which can be used to describe how people feel. Beside each statement are four numbers which indicate how often each statement is true of you (e.g., 1 = not at all, 2 = A little, 3 = Moderately, 4 = very much so). Please read each statement carefully and circle the number which best indicates how often, in general, the statement is true of you.

1. My heart beats fast
2. My muscles are tense
3. I feel agonized over my problems
4. I think that others won’t approve of me.
5. I feel like I’m missing out on things because I can’t make up my mind soon enough.
6. I feel dizzy.
7. My muscles feel weak.
8. I feel trembly and shaky.
9. I picture some future misfortune.
10. I can’t get some thought out of my mind.
11. I have trouble remembering things.
12. My face feels hot.
13. I think that the worst will happen.
14. My arms and legs feel stiff.
15. My throat feels dry.
16. I keep busy to avoid uncomfortable thoughts.
17. I cannot concentrate without irrelevant thoughts intruding.
18. My breathing is fast and shallow.
19. I worry that I cannot control my thoughts as well as I would like to.
20. I have butterflies in the stomach.
21. My palms feel clammy.
APPENDIX C:

THE ABBREVIATED MATH ANXIETY SCALE

(Hopko, Mahadevah, Bare, & Hunt, 2003)
The Abbreviated Math Anxiety Scale (AMAS)

Please rate each item below in terms of how anxious you would feel during the event specified.

1 = Low Anxiety, 2 = Some Anxiety, 3 = Moderate Anxiety, 4 = Quite a bit of Anxiety, 5 = High Anxiety

1. Having to use the tables in the back of a mathematics book.
2. Thinking about an upcoming math test one day before.
3. Watching a teacher work an algebraic equation on the blackboard.
4. Taking an examination in a mathematics course.
5. Being given a homework assignment of many difficult problems which is due the next class meeting.
6. Listening to a lecture in mathematics class.
7. Listening to another student explain a mathematics formula.
8. Being given a “pop” quiz in a mathematics class.
APPENDIX D:

DEMOGRAPHIC SURVEY
Demographic survey

1. Age: _______

2. Sex: Male  Female  Decline to answer

3. Class Standing: Freshman  Sophomore  Junior  Senior

4. Major 1: __________________________  Major 2: __________________________

Minor(s): ________________________________________________

5. What is the highest level of math that you have reached or are currently enrolled in? (e.g., College Algebra, Calculus, Statistics)

____________________________________________________________

6. Ethnicity: ______________________________

7. Handedness: Left-dominant  Right-dominant

8. How fluent are you in English? (circle level)
   Not fluent at all->1-------2------3------4-------5<-Native fluency

9. Other language(s) spoken: _____________________________

10. Have you ever been diagnosed with psychological/neurological condition (e.g., Depression, Anxiety disorder, Discalculia, etc.) by a professional?  
    (PLEASE CIRCLE ONE ➔)  Yes / No

11. If you answered Yes (to question 10):
    a. please list condition(s):

    __________________________________________________________

    b. list prescription medications you are taking for condition(s):

    c. have you received any CSUSB disability services for condition(s) listed?:
       Yes / No
APPENDIX E:

INSTITUTIONAL REVIEW BOARD LETTER OF APPROVAL
July 8, 2019

CSUSB INSTITUTIONAL REVIEW BOARD
Expedited Review
IRB-FY2019-295
Status: Approved

Pilar Olid
Hideya Koshino
Department of CSBS - Psychology
California State University, San Bernardino
5500 University Parkway
San Bernardino, California 92407

Dear Pilar Olid

Your application to use human subjects, titled “Working Memory Capacity and Numerical Processing Moderate the Relationship Between Math Anxiety and Math Performance” has been reviewed and approved by the Institutional Review Board (IRB). The informed consent document you submitted is the official version for your study and cannot be changed without prior IRB approval. A change in your informed consent (no matter how minor the change) requires re-submission of your protocol as amended using the IRB Cayuse system protocol change form.

Your IRB proposal IRB-FY2019-295 - Working Memory Capacity and Numerical Processing Moderate the Relationship Between Math Anxiety and Math Performance is approved. You are permitted to collect information from 150 participants for extra credit from CSUSB. This approval is valid from 7/8/2019 to 7/7/2020.

Your application is approved for one year from July 8, 2019 through

Please note the Cayuse IRB system will notify you when your protocol is up for renewal and ensure you file it before your protocol study end date.
Your responsibilities as the researcher/investigator reporting to the IRB Committee include the following 4 requirements as mandated by the Code of Federal Regulations 45 CFR 46 listed below. Please note that the protocol change form and renewal form are located on the IRB website under the forms menu. Failure to notify the IRB of the above may result in disciplinary action. You are required to keep copies of the informed consent forms and data for at least three years.

You are required to notify the IRB of the following by submitting the appropriate form (modification, unanticipated/adverse event, renewal, study closure) through the online Cayuse IRB Submission System.

1. If you need to make any changes/modifications to your protocol submit a modification form as the IRB must review all changes before implementing in your study to ensure the degree of risk has not changed.
2. If any unanticipated adverse events are experienced by subjects during your research study or project.
3. If your study has not been completed submit a renewal to the IRB.
4. If you are no longer conducting the study or project submit a study closure.

Please ensure your CITI Human Subjects Training is kept up-to-date and current throughout the study.

The CSUSB IRB has not evaluated your proposal for scientific merit, except to weigh the risk to the human participants and the aspects of the proposal related to potential risk and benefit. This approval notice does not replace any departmental or additional approvals which may be required. If you have any questions regarding the IRB decision, please contact Dr. Jacob Jones, Assistant Professor of Psychology. Dr. Jones can be reached by email at jacob.jones@csusb.edu. Please include your application approval identification number (listed at the top) in all correspondence.

Best of luck with your research.

Sincerely,

Sincerely,

Donna Garcia

Donna Garcia, Ph.D., IRB Chair
CSUSB Institutional Review Board

DG/MG
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