THE UNIVERSITY OF CHICAGO

THE ROLE OF MATH ANXIETY AND SITUATIONAL ANXIETY IN MATH PERFORMANCE

A DISSERTATION SUBMITTED TO

THE FACULTY OF THE DIVISION OF THE SOCIAL SCIENCES

IN CANDIDACY FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

DEPARTMENT OF PSYCHOLOGY

BY

ANDREA THERESE HENRY

CHICAGO, ILLINOIS

DECEMBER 2017

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

My journey through graduate school has been anything but ordinary. I would like to extend my deepest gratitude for my two advisors: Dr. Sian Beilock and Dr. Dario Maestripieri. You took a chance on me, and I am forever grateful for that. I've learned a great deal working with you and will cherish the lessons I've learned over the past four years, both academic and otherwise. To Dr. Susan Levine, thank you for helping me navigate my first year of graduate school and for guiding me toward the labs that I ended up calling 'home'. Your support allowed me to pursue my dream. To Dr. Greg Norman, your questions and discussion helped greatly in my scientific endeavors. Perhaps more importantly, your levity and kindness were always appreciated.

I would like to thank my lab members across both the Maestripieri and Beilock labs. I would also like to thank the lifelong friends I have met in graduate school. To Carlos Cardenas, you are a shining star, and I'm so lucky to have met you. To Talia Berkowitz, your friendship over my final year of graduate school helped pull me through. To Sean Coye, thank you for your steadfast friendship and for the hilarity you bring to my life; you brighten my days. To Nora Nickels, you are a brilliant example of what a genuinely kind and loving person is; I'm so grateful that luck brought us together. To Jason Sattizahn, you are the absolute best; my life is exceptionally better because you are in it.

Lastly, I need to thank my wonderful family and friends outside of graduate school. I have an army of exquisitely warm and genuine people behind me who have made this possible. To my mom, you have been my inspiration since I was little, not only to go after my dreams as an independent woman, but to also remain kind and genuine as I pursue those dreams. Your model and unconditional love have been beyond important both in my life and in academia. You are a rock star in my life. To my dad, your constant support of my research and of my life journey overall has been unwavering. Thank you for keeping me motivated, pushing me toward positivity, and helping me to appreciate the small victories. I am so fortunate and grateful to have such an amazing relationship with you. To my sister Lauren, you know me better than anyone; this closeness and your genuine empathy for my experience are an integral part of my life that I could not live without. You pushed me across the finish line for my doctorate, and you push me to be a better person in all my life endeavors. To Rachael, there aren't words. You're the best friend anyone could have; I truly wouldn't be where I am today without you. I love you beyond measure. To Lauren, you've made the last five years in Chicago more vibrant and fun, and I can't believe luck (i.e. fate) brought us together! From the bottom of my heart, I absolutely cherish our friendship. To Carol and Luke, I recognize how lucky I am to have you, and I love you dearly. To my extended family, you're the best. I have an army of support behind me, and I desperately love you all. You have made me who I am today. Lastly to Rome, your doggy cuddles made the sleepless nights bearable!

ABSTRACT

Math anxiety is a specific tension, apprehension, or fear surrounding math. Math anxiety is negatively related to math performance, such that those who are highly math anxious show poorer performance in basic numerical processing and perform worse on complex math problems as compared to those who are low in math anxiety. Math anxiety is a trait anxiety, in that some individuals have higher levels of persistent anxiety overall than others, which in this case is specifically related to math. Reductions in working memory

, a limited-capacity executive resource used for the immediate storage, integration and manipulation of information, are seen in math anxious individuals when solving math problems. It is not just trait anxiety that relates to performance. Situational anxiety induced from the environment has also been shown to negatively impact math problem-solving due to the effects of anxiety on working memory resources. Importantly, math problems are often solved in high pressure environments where an individual needs to perform at her best. Little research has explored how situational anxiety induced from the environment may interact with trait math anxiety to impact math performance. In experiment 1 we demonstrate that undergraduate adults who are high in math anxiety show reductions in math performance on high cognitively demanding problems in a low pressure situation, and math performance does not decline further with situational pressure. In experiment 2 we demonstrate that children who are high in math anxiety and high in WM show declines in math performance if they report high levels of state anxiety following a math interaction they completed with their parent. Children who are high in math anxiety and high in WM who report low levels of state anxiety following a math interaction perform similarly to those children who are high in WM and low in math anxiety. Similar effects are seen in high WM children if parents report high levels of state anxiety and math anxiety,

though the effects are small and not significant. In experiment 2 we also demonstrate that parents show declines in their own math performance following a math interaction with their child that are modified by the parent's math anxiety and by the situational pressure induced by the interaction. Parent's in the low pressure condition with high math anxiety showed declines in math performance as compared to parents with low math anxiety. In the pressure condition, low math anxious parents perform similarly to high math anxious parents in the low pressure condition. High math anxious parents in the pressure condition show the lowest math performance. Our results in the first experiment do not suggest a compound effect of trait math anxiety and state anxiety/pressure on performance, but this may be due to increased pressure they feel in what we consider a 'low pressure' condition. Our results in experiment 2 demonstrate a compound effect of math anxiety and state anxiety/pressure on math performance in both children and parents. Importantly, when highly math anxious children report low levels of state anxiety following a math interaction completed either under low or high pressure, they perform similarly to low math anxious children. When high math anxious parents report low levels of state anxiety following a low pressure situation, they also performed similarly to low math anxious parents, though this is not significant. Ultimately, the negative effects of math anxiety on math performance may be alleviated if an individual's reported perceptions of their anxiety are low. In order to help improve math performance for math anxious individuals, interventions may focus on off-loading an individual's worries in order to reduce perceptions of anxiety or may focus on helping math anxious individuals reinterpret their anxiety prior to performing math. This may be particularly beneficial for children who are highly math anxious.

INTRODUCTION

Math Anxiety: Definition, Prevalence & Performance Implications

Anxiety is characterized as an 'aversive emotional state' that occurs in threatening situations (Eysenck et al., 2007). Levels of anxiety can vary within an individual across time throughout different circumstances (i.e. state anxiety), with some circumstances inducing higher levels of anxiety than others. Anxiety can also vary between individuals on a trait level, such that some individuals have higher levels of persistent anxiety overall than others. Trait anxiety can differ by domain, that is, people can have a specific trait anxiety related to a particular topic, such as test anxiety or math anxiety. Math anxiety is defined as a specific tension, apprehension, or fear surrounding math (Ashcraft, 2002). Math anxiety is prevalent in society, and its prevalence has been increasing over time. According to the Programme for International Student Assessment (PISA), which surveys 15 year olds in 65 countries and varying economies, 31% of the surveyed population reported that they get nervous doing math problems, 30% reported that they feel helpless when doing math problems, and 33% reported that they get very tense when they have to do math homework. In 2003, 29% of students reported getting very tense when doing math homework, and by 2012 that number had grown to 32% (OECD: PISA 2012 Results). Within the United States, a majority of adults report a dislike and fear of mathematics (Burns, 1998; Zaslavsky, 1994). Math anxiety develops during childhood (Maloney & Beilock, 2012), and it has been reported in children as young as first grade (Ramirez et al., 2013).

The prevalence of math anxiety is troubling because math anxiety has significant behavioral consequences. Individuals who are high in math anxiety tend to avoid math related careers and avoid math in general, have lower math grades, and show lower math achievement on standardized tests (Hembree, 1990; Ashcraft & Moore, 2009). Research has shown that a bidirectional or reciprocal relationship exists between math anxiety and math performance. That is, poor math performance can contribute to greater anxiety surrounding math, and greater math anxiety can contribute to poor math performance as compared to the performance of low math anxious individuals. To try to tease apart the bidirectional relationship between math performance and math anxiety, Faust, Ashcraft and Fleck (1996) show that when performing whole number arithmetic without time pressure, individuals high in math anxiety perform similarly to low math anxious counterparts. Yet another study demonstrated similar math performance between high and low math anxious individuals on math problems low in difficulty. However, when problems increase in difficulty, math performance declines for those individuals who are high in math anxiety (Ashcraft & Moore, 2009). Ultimately, it is not simply that highly math anxious individuals show a lower overall math competence, but that they underperform when a situation contains both a high degree of pressure and requires solving relatively more difficult math problems.

Questions of Interest

To our knowledge, no research has explored how math anxiety impacts performance in a pressure situation that induces situational state anxiety. There are different ways in which individuals with math anxiety may experience situational anxiety. Individuals with high math anxiety experience pressure situations throughout their lives in which they themselves need to perform at their best, situations that include math tests in school, standardized tests to measure achievement, and entrance exams for post-secondary school. For younger children who have not become familiarized with testing situations in school, homework situations surrounding math may induce situational pressure for children who are highly math anxious. When highly math anxious individuals become parents, they may too experience situational pressure to help their children perform well on math homework assignments. In the current work I aimed to determine how math anxiety and pressure interact to impact the math performance of math anxious adults. Additionally, I aimed to determine how situational pressure interacts with children's own math anxiety and the math anxiety of their parents to affect children's math performance. I also aimed to determine what cognitive mechanisms may be associated with poorer math performance for math anxious adults and for children who are highly math anxious or whose parents are highly math anxious.

Experimental Outline

To examine these questions, two experiments were conducted in two different populations of math anxious individuals. The first experiment explored math anxiety and its effects on math performance in undergraduate adults. Situational pressure was induced in the laboratory using a paradigm that has been well-documented to increase perceived state anxiety and affect math performance. Cognitive mechanisms were examined both by measuring an executive resource of the individuals completing the math task and by using a math task that places different demands on the cognitive resources necessary for completing the task. The second explored math anxiety in both parents and children and its effects on both parents and children's math performance following a homework-like situation designed to either induce pressure or alleviate pressure. Cognitive mechanisms were explored in children by measuring an executive resource implicated in math performance. Cognitive mechanisms were explored in parents by using the same math task utilized in experiment 1 that places different demands on the cognitive resources necessary for completing the task.

Before outlining the specific aims for experiment 1, I begin with a discussion on one particular executive resource that has been implicated in declines in math performance. I then discuss its association with anxiety. I go on to discuss the research that has explored declines in math performance when experiencing trait math anxiety or state anxiety and the cognitive mechanisms associated with these declines. Before outlining the specific aims for experiment 2, I discuss children's math anxiety, the associations between children's math anxiety and children's math performance, and the cognitive mechanisms that associated with declines in math performance in young children with math anxiety. I discuss research that has demonstrated the impact of parent math anxiety on children's math performance. I then discuss the research that suggests homework interactions may induce a situational anxiety in parents and children when interacting over math homework. Lastly, I describe recent work that suggests alleviating situational anxiety surrounding homework may alleviate the negative effects of parent math anxiety on children's math performance.

Working Memory & Performance

To explore the effects that anxieties (i.e. trait math anxiety and state anxiety) have on performance, I look to cognitive mechanisms that underlie behavioral performance. One particularly prominent cognitive resource that has been implicated in performance breakdown is Working Memory (WM). Working memory is a limited-capacity executive resource used for the immediate storage, integration and manipulation of information (see Miyake & Shah, 1999 for a review). There are differences in WM resources between individuals, such that some individuals have higher WM resources than others. These WM resources are necessary for complex cognitive tasks (Miyake & Shah, 1999), such as solving math problems that involve the integration and manipulation of information (Hitch, 1978; DeStefano & LeFevre, 2004; Wiley & Jarosz, 2012). Hitch (1978) implicated WM in math problem solving by demonstrating that individuals break up problems into stages, which requires the temporary storage of information.

Furthermore, when individuals were required to maintain those partial results over a period of time, interim knowledge was forgotten, implicating the necessity of temporary storage for accurate problem-solving. The role of WM was further implicated in math problem solving by increasing the cognitive load through a dual-task procedure. Individuals who completed simple subtraction problems while simultaneously remembering two, four, or six-letter strings showed more errors when they had to recall 6 letters as compared to 2 or 4 letters. Ultimately, when the two tasks competed for the same WM resources, performance declined when WM was taxed with greater storage in the dual-task procedure (Seyler et al., 2003). Further dual-task studies demonstrated decrements in performance on multiplication and division problems (Imbo & Vandierendonck, 2007) and multi-digit problems that involve a sequence of steps related to carrying and borrowing (Imbo et al., 2007). Ultimately, when WM is loaded through a secondary, simultaneous task, math performance declines on math problems that rely on WM to arrive at an accurate solution. In summary, WM is implicated in math problem-solving, particularly when solving math problems that are complex or demanding of WM resources.

Anxiety & Working Memory: Mechanism of Performance Breakdown

The impact of anxiety, both math trait anxiety and state anxiety, upon WM resources stands as a likely mechanism through which math performance declines when an individual experiences anxiety. Processing Efficiency Theory has linked anxiety (trait math anxiety and state anxiety) to WM through its impact on the amount of WM resources available to perform a task (Eysenck & Calvo, 1992). Specifically, it is argued that anxiety induces worry within an individual, and these worrisome thoughts and ruminations reduce an individual's processing efficiency, which is defined as the relationship between how effective a performance is and the resources spent on task performance. That is, when an individual experiences anxiety more cognitive resources are necessary to perform the task at hand, which typically results in slower response times. Ultimately, worrisome thoughts or verbal ruminations consume WM resources that would otherwise be used for the task at hand, and this consumption of WM resources negatively impacts task performance on cognitively demanding tasks (DeCaro et al., 2010). As such, WM has been implicated in performance declines when an individual experiences either trait or state anxiety.

Math Anxiety, Working Memory & Performance

Math anxiety was demonstrated to have detrimental, on-line cognitive effects when solving math problems (Faust et al., 1996), such that the time required to solve problems that require a carry operation increases for individuals with higher math anxiety. It was argued that these effects were due to depletions in WM resources. Ashcraft and Kirk (2001) more directly examined the on-line cognitive effects of math anxiety on math performance. They demonstrate in a first experiment that individuals who were high in math anxiety show decreases in WM when completing a WM task that was computationally based, though not when completing a WM task that was verbally based. In a second experiment, participants were placed in a dual-task scenario requiring participants to complete addition problems that varied in difficulty (i.e. from basic addition to problems that involved carry operations) while also holding either two or six letters in memory for future recall. High math anxious individuals whose WM was taxed with a secondary task showed declines in performance on difficult problems that also taxed WM. Low math anxious individuals showed declines in performance on difficult problems when completing the secondary task, though declines were not as pronounced as in high math anxious individuals. In summary, math anxiety is associated with on-line decrements in WM for those individuals who are particularly high in math anxiety. It is argued that when highly math anxious individuals perform math problems, they experience worrisome thoughts and ruminations related to performance that draw their limited WM resources away from the task at hand. These performance related worries are associated with declines in math performance due to their effects on WM (Hopko et al., 1998).

State Anxiety, Working Memory & Performance

The effects of state anxiety or situational anxiety on performance have been shown to impact performance after creating an environment where an individual must perform at his or her best. Gimmig et al. (2006) show that when individuals are put under pressure by telling participants that performance is indicative of analytical reasoning, there are declines in performance on Raven's Standard Progressive Matrices as compared to the performance of individuals who are not told that their performance is indicative of analytical reasoning. Coy et al. (2011) also demonstrate performance declines when under pressure, such that when participants are put under pressure and told their performance is being evaluated, they report greater anxiety and also exhibit lower performance on tasks that tax WM, including a Digit Span Task and a Stroop Colour-Word Task. Decrements in math performance in particular have been observed in anxiety-inducing situations when pressure is put on an individual to perform at an optimal level. Beilock and Carr (2005) had participants complete a set of math problems that varied in the demand they placed on WM (i.e. cognitive demand) in both a low pressure situation and then in a high pressure situation. Accuracy on math problems that were high in cognitive demand declined when participants were put under pressure, but this was only observed in those individuals with high WM capacity. Furthermore, no effects of pressure were observed on low-demand problems. Overall, situational pressure to perform results in lower accuracy on math problems that rely heavily on WM resources, whereas accuracy is not affected on problems that do not require WM. These effects are observed for those individuals who are high in WM resources. In other words, state anxiety induced in a pressure situation results in math performance declines when problems are cognitively demanding and when individuals are high in WM. These results implicate WM as the cognitive mechanism leading to math performance declines when individuals experience situational state anxiety; state anxiety is associated with on-line decrements in WM for high WM individuals. A similar argument has been made to that described regarding math anxiety that the situational state anxiety induced under pressure creates worries and ruminations that compromise WM resources that would otherwise be used to complete the task at hand (Coy et al., 2011; Ramirez & Beilock, 2011). These declines in WM resources result in lower math performance (Beilock & Carr, 2005; Beilock & DeCaro, 2007).

Anxiety & Optimal Performance

Importantly, evidence suggests that anxiety is not uniformly associated with declines in performance. The Yerkes-Dodson Law asserts that there are differential effects of anxiety on performance that rely on the amount of anxiety an individual experiences. Low levels of anxiety and extreme levels of anxiety are both associated with poor performance, whereas anxiety levels that lie between these extremes are associated with optimal performance. The argument is that as arousal increases, attentional and motivational factors increase and performance increases to a point. When arousal becomes too extreme, attention shifts toward the threatening stimulus and performance suffers. Importantly, evidence suggests that declines associated with extreme arousal under the Yerkes-Dodson Law occur when completing a task that is particularly difficult (Yerkes & Dodson, 1908; Broadhurst, 1959; Deshpande & Kawane, 1982; Teigen, 1994; Eysenck et al., 2007). The cognitive mechanisms outlined above that account for performance declines related to both math anxiety and situational anxiety are described by a distraction account, whereby attention shifts under pressure from the primary task at hand to irrelevant cues, such as worries, which results in declines in WM resources and in turn declines in performance (Beilock et al., 2004). The aforementioned studies that link math anxiety and situational anxiety to declines in performance assume that math anxiety or pressure situations induce anxiety levels that reach a debilitative arousal state within an individual that shifts attention toward an individual's worries and ruminations, which ultimately compromises WM resources (as described above). These assumptions have been indirectly supported in the pressure studies as subjective measures have been collected that support increased reports of state anxiety in individuals following pressure situations and declines in performance. However, to my knowledge, no studies have measured state anxieties in math anxious individuals directly after completing a math task and related these state anxieties to performance. This is an important question to consider as it is possible that not all math anxious individuals feel higher state anxiety when performing math as compared to low math anxious individuals, or it is possible that math anxious individuals experience anxiety levels that are above and beyond those of low math anxious individuals when performing math. Additionally, it remains unclear what amount of state anxiety within math anxious individuals becomes debilitating.

Experiment 1: Aims

In experiment 1, I aim to explore whether highly math anxious adults experience greater state anxiety as compared to low math anxious individuals within a pressure situation where they have to perform math. As previously described, highly math anxious adults show declines in math performance compared to low math anxious adults. Additionally, state anxiety induced from a pressure scenario is associated with declines in math performance overall. However, it remains unclear whether highly math anxious adults show lower performance than low math anxious individuals after experiencing additional state anxiety. It is possible that there is a compound effect of math anxiety and state anxiety on performance, such that highly math anxious adults perform even lower under pressure than low math anxious adults. It is also possible that highly math anxious adults will show initially low math performance in a low pressure scenario and the additional pressure does not further affect math performance. In this scenario, highly math anxious adults may show lower math performance under low pressure than low math anxious adults, due to the debilitative anxiety that may be experienced in even low pressure situations. Upon experiencing pressure and increased state anxiety that may mirror that of high math anxiety adults under low pressure, the performance of low math anxious adults may decline to levels similar to that of highly math anxious adults.

Children's Math Anxiety: Relation to Performance and Working Memory

The majority of work that has explored math anxiety has focused predominantly on college, high school, and middle school students (Wigfield & Meece, 1988; Hopko et al., 1998; Change & Beilock, 2016; Ashcraft & Kirk, 2001; Maloney & Beilock, 2012; Ashcraft & Moore, 2009; Ashcraft, 2002; Ashcraft & Krause, 2007; Hembree, 1990). Although little research has focused on math anxiety in young children, math anxiety has been identified and measured in children as young as elementary school (Jameson, 2014; Jansen et al., 2013; Ramirez et al., 2013; Wu et al., 2012; Vukovic et al., 2013). Not only has math anxiety been identified in children of such a young age, but it has been linked to children's math achievement. Wu et al. (2012) found that higher levels of math anxiety in second and third grade children were negatively associated with children's math achievement. Vukovic et al. (2013) measured math anxiety in second graders and found a significant negative relation between children's math anxiety and math performance on a measure regarding calculation skills and on a mathematical applications measure. It was also found that math anxiety measured in second grade for these children predicted their math performance on the mathematical applications measure the following year, though only for children who were high in WM. Ramirez et al. (2013) report math anxiety in children as young as first grade and also demonstrate a negative relation between children's math anxiety and children's math achievement. Interestingly and in line with the results of Vukovic et al. (2013), the negative relation between math anxiety and math achievement is moderated by children's WM capacity. Those children who are high in WM show decreased math achievement if they are also highly math anxious. These results indicate that math anxiety in children affects children's math performance, and it is likely through similar cognitive mechanisms by which math anxiety affects math performance in adults. That is, high math anxiety in younger children depletes WM resources in those individuals with high WM capacity. As WM resources in children have been greatly linked to a child's math performance (McLean & Hitch, 1999; Holmes & Adams, 2006; Rasmussen & Bisanz, 2005; Gathercole & Pickering, 2000), these declines in WM resources due to the anxiety a child experiences ultimately result in lower performance (Owens et al., 2008).

Parent's Math Anxiety: Relation to Children's Math Performance

Not only have children's own levels of math anxiety been linked to declines in children's math achievement, but parent's levels of math anxiety have been demonstrated to have detrimental effects on children's math achievement. Children of highly math anxious parents show reduced achievement and growth across the school year as compared to children of low math anxious parents (Maloney et al., 2015). These effects are particularly prominent when children are receiving a large amount of math homework help from their math anxious parents. Ultimately, when math interactions surrounding homework occur, the negative effects of math anxiety on math performance transfer to the children of math anxious parents. These results suggest that interactions surrounding math with a high math anxious parent contribute to poor math achievement in children.

Homework & Anxiety/Stress

To determine how interacting over homework leads to declines in math achievement over the year, I look to related research on homework interactions between parents and children. Overall, homework help from parents has been associated both with positive and negative effects on achievement (Patall et al., 2008). It has been argued that the negative effects of homework help on achievement may stem from tension or confusion that is caused by the parental input in homework situations (Solomon et al., 2002; Patall et al., 2008; Pressman et al., 2015). Tension between parents and children surrounding homework is compounded when parents feel they do not have the adequate skills necessary to appropriately help their child (Patall et al., 2008). A large survey study with children in grades K-12 extended these findings by demonstrating that family stress increased as homework load increased, particularly if parents feel limited in their capacity to help their child (Pressman et al., 2015). Additionally, qualitative interviews collected in teenagers from eleven to sixteen years old demonstrated that parents feel pressure in terms of the need to help their children achieve high marks on homework assignments (Solomon et al., 2002). Taken together, these results suggest that homework help can be stressful for children and parents, particularly if parents do not feel that they can adequately support their child with their own skills. It is possible that for highly math anxious parents, helping their child with math homework that will be graded and will influence their child's academic trajectory creates a situational state anxiety, particularly because they may not feel as though they have the adequate knowledge or skill set surrounding math to help their child with their math homework. To our knowledge, no in lab studies have explored whether parents experience increased state anxiety following a homework-like interaction and no studies have explored how trait math anxiety may relate to this experience of state anxiety.

A recent study showed that an in-home, low pressure intervention can help alleviate the negative effects of homework help from highly math anxious parents on children's achievement. This study utilized a math intervention tool to improve math achievement in first graders through the use of an iPad application (app) (Berkowitz et al., 2015). Parents used this app to interact with their children to solve numerical story problems. Importantly, the math problems performed on the iPad were very low pressure in that parents and children moved at their own pace when solving problems, and the answers were provided for them immediately after working on them. The math work of the children was not graded by a teacher, and it did not have future consequences for the child (i.e. affect which math classes the student can take in the future), which may be particularly anxiety-provoking for math anxious parents. The study found that greater weekly app use was associated with more growth in math achievement across the year for children of highly math anxious parents as compared to children of highly math anxious parents who used the app less than 0.51 times/week. Despite the positive effects that the math app had on math achievement for children of highly math anxious parents, it was not directly tested whether the math app was indeed a low pressure interaction or if the low pressure interaction surrounding the math app was responsible for increased math achievement.

Experiment 2: Aims

In experiment 1 I explore how an adult's math anxiety interacts with induced state anxiety to affect their own math performance. In experiment 2, I examine how math anxiety of both children and parents affects children's math performance following a parent/child interaction designed to increase state anxiety. Although math anxiety has been demonstrated in children as young as first grade and has been linked to negative math performance, no studies to our knowledge have attempted to induce a situational state anxiety within children through a homework scenario to determine how this may affect math performance, possibly through its interaction with children's math anxiety. Within certain schools, the transition to elementary school is associated with the beginnings of homework assignments, to which children prior to first grade may not yet have been exposed. A homework scenario serves as a possible avenue through which to explore induced state anxiety on children's math performance as it may be considered a stressful situation in which young children feel they have to perform well to achieve high math marks. Additionally, it has been shown that children show poorer academic achievement when they spend more time interacting over homework with math anxious parents, regardless of the child's own math anxiety levels. Research from related fields demonstrates that homework help can be a source of tension, stress, and pressure for families, and a recent study demonstrates that low pressure math interactions at home with highly math anxious parents alleviated the negative effects of parent math anxiety on student achievement. It is possible that interacting in a pressure situation over math increases state anxiety in parents, and that this experience of state anxiety is greater for parents with high math anxiety. It may also be possible that parents with high math anxiety may not experience greater state anxiety in a pressure situation due to the heightened anxiety they feel when performing math in a low pressure scenario. Regardless, trait math anxiety of the parents and situational state anxiety created through a math homework interaction may have compound effects on children's math performance if it is in fact the case that the pressure component of interacting over math with their child is responsible for decreases in children's math performance.

Summary & Project Motivation

To summarize, math anxiety is a trait anxiety that negatively impacts math performance, particularly for those problems that are more difficult and require WM resources to arrive at the answer. State anxiety is a situational anxiety induced from the environment, typically in a pressure scenario, that has also been associated with decreased math performance for cognitively demanding math problems. There are different domains in which individuals with math anxiety may experience situational anxiety. Individuals with high math anxiety experience pressure situations throughout their lives in which they themselves need to perform at their best, situations that include math tests in school, standardized tests to measure achievement, and homework interactions for young children. When high math anxious individuals become parents, they may experience situational pressure to help their children perform well on math homework assignments. Despite the parallel findings of reduced math performance due to both trait math anxiety and situationally induced state anxiety, no research has explored how these two types of anxieties may interact to impact the math performance of math anxious individuals themselves or the math performance of children who either personally experience high levels of math anxiety or whose parents are highly math anxious.

EXPERIMENT 1

I aimed to test how math anxiety and situational anxiety interact to affect math performance of adults in the lab and to relate math performance to WM. To test this, participants came in for two testing sessions. In the first testing session, participants completed two blocks of math problems. The first block was performed under low pressure, and the second block was performed under a high degree of pressure. Accuracy and reaction time were measured in the math task. Math anxiety was measured in all participants prior to their arrival in the lab. State anxiety was measured prior to beginning the math task and following the math task. In a second testing session, WM was measured in all participants.

I hypothesized that individuals with high math anxiety would experience greater state anxiety than low math anxious individuals when performing math under pressure. In regard to math performance, I hypothesized that individuals with high math anxiety would show lower math performance than low math anxious individuals in a low pressure scenario. In regard to performance under high pressure, two potential hypotheses are possible. It is possible that individuals with high math anxiety would show a similar decline in math performance to low math anxious individuals when under pressure, that is they would drop their math performance under pressure. It is also possible that individuals with high math anxiety would not show a further drop in performance under pressure, almost as if their performance under low pressure was as a baseline level that could not be further affected by situational anxiety. When breaking up the results further into low and high WM individuals who are both low and high math anxious, I hypothesized that high WM individuals who were low math anxious would drive the decline in problems of high cognitive demand under pressure (as demonstrated in Beilock & Carr, 2005).

Methods

Participants

Participants were recruited from the Chicago, IL area surrounding the University of Chicago campus and the Lansing, MI area surrounding Michigan State campus. Data for a total of 95 participants (age range: 18-35 years old) were collected over a year. After excluding participants who completed less than 80% accuracy on the WM tasks, failed to complete the WM tasks, or scored 3 or more standard deviations from the mean on an additional executive functioning task, behavioral data from 83 participants (49 female; age: M=23.11, SD=4.50) were analyzed. Participants were paid $25 dollars for their participation in the two sessions. This study was approved by the Institutional Review Board at both the University of Chicago and Michigan State University.

Materials

Questionnaires: Prior to arriving in the lab, participants completed a prescreening battery of questionnaires online that included demographic questions, a math anxiety questionnaire (sMARS; Alexander & Martray, 1989), a trait anxiety questionnaire (STAI-T: Spielberger & Gorsuch, 1983), and additional filler questionnaires. In the first lab session prior to completing the math task and again following the math task, participants completed a state anxiety questionnaire (STAI-S: Spielberger & Gorsuch, 1983). All questionnaires were administered online.

Working Memory Measures: In the second lab session participants completed two WM tasks, the results from which were averaged in order to determine an individual's WM score and ultimately measure individual differences in WM capacity. The two tasks that were used were an automated Operation Span Task (OSPAN; Turner & Engle, 1989; Unsworth, et al., 2005) and an automated Reading Span Task (RSPAN; Daneman & Carpenter, 1980). Each of these follow a dual-task procedure in which participants make judgments about whether a mathematical operation is true (OSPAN) or a sentence makes logical sense (RSPAN). In each trial, participants make a judgment about the presented stimuli and then a letter is presented on the screen. At the end of the trials for that run, participants recall the letters that were presented in perfect order. A run would range anywhere from 3-7 trials, which means that participants had to recall anywhere from 3-7 letters on each run. Participants final OSPAN and RSPAN consist of the total number of letters that were perfectly recalled when they were able to perfectly recall a whole trial. A final WM score was computed through averaging a participant's OSPAN and RPSAN scores. The WM tasks were presented using E-Prime software (Psychology Tools, Inc.).

Procedure

In session 1, upon arrival into the lab, participants filled out a consent form and were seated at a computer where they completed a set of questionnaires that included an initial state anxiety questionnaire (STAI-S: Spielberger & Gorsuch, 1983). This initial measure of state anxiety was collected as a baseline measure of state anxiety, to which the state anxiety measure collected following the pressure induction was compared. The additional surveys were used to mask from the participant the study's link to anxiety, and therefore they were not analyzed.

After completing the initial surveys, participants completed an additional cognitive task that measured attentional control, which will not be analyzed or discussed here. They then completed two block of modular arithmetic (MA) task (Gauss, 1801, as described in Beilock et al., 2004). MA involves judging the validity of problems that take on a particular format, such as $18 \equiv 6 (\text{mod } 3)$. To solve this problem, the middle number is subtracted from first (e.g. 18-6). The remainder of the subtraction is then divided by the mod number (e.g. 12/3). If the result or dividend is a whole number (e.g. 4), the statement is true. Otherwise the statement is false. MA was utilized in this experiment as it allows WM demands to be manipulated. Increased WM demands can be induced by using larger numbers and borrow operations in the statement, as these problems involve greater intermediate steps and require a larger amount of information to be maintained in WM (Beilock & Carr, 2005). The participant completed two blocks of forty MA problems that were presented horizontally. Within each of these blocks, half of the problems were of high cognitive demand and the second half were of low cognitive demand. The problems used in the two blocks were counterbalanced across subjects. Accuracy and reaction time were recorded in both blocks of problems. The MA problems were presented using E-Prime software (Psychology Tools, Inc.).

Between the two blocks of MA problems, a pressure induction took place, similar to that described in Beilock & Carr (2005). To induce pressure, participants were told they could make an additional $10 if they and another participant (who was not in fact a real participant) each improved their math performance from the first block by 20%. Importantly, they were led to believe that this fictitious participant had already completed the problems and had already achieved the 20% increase in accuracy. If the participant did not improve his or her accuracy, he or she was led to believe that neither s/he nor the fictitious participant would receive an additional $10, despite the fact that the other 'participant' had already achieved this goal. Additionally, the participants were videotaped while they performed the second block of MA problems, and they were told that teachers and professors were interested in examining these videos. Following this induction, the second block of MA problems were completed. Lastly, subjects completed a second anxiety questionnaire (STAI-S: Spielberger & Gorsuch, 1983).

Participants returned for session 2 at least two days later in order to complete the WM tasks. They completed the automated OPSAN and RSPAN, which were administered via E-Prime software (Psychology Tools, Inc.). After they completed these tasks, a manipulation check was completed to determine if participants were suspicious about the pressure induction. No participants were removed from the analyses based on this suspicion check. Finally, participants were debriefed, and they were reimbursed $25 for their time, regardless of whether their MA performance actually improved from low pressure to high pressure.

Results

Data Transformations

Math anxiety ratings in the sample were in line with published norms (M=36.06, SD=19.06, range=6-99; Alexander & Martray, 1989: M= 31, SD=16). The math anxiety ratings from this sample were positively skewed, as such math anxiety ratings were square root transformed. The transformation resulted in a normal distribution of math anxiety ratings in the sample. For all analyses relating to math anxiety scores, the square root transformed data were used. WM scores in the sample were moderately negatively skewed (M=48.69, SD=16.42, range=5-72). As such, WM were also square root transformed, which resulted in a normal distribution of WM scores in the sample. Therefore, for all analyses relating to WM, the square root transformed data were used.

Anxiety Ratings and Pressure Manipulation

To determine whether the pressure manipulation had an effect, a repeated measures ANOVA was run in which pressure was treated as a within-subjects variable and STAI-S (state anxiety) ratings were treated as the dependent variables. Overall there was a significant effect of the pressure manipulation on ratings of anxiety: $F(1, 81) = 44.53$, $p = < 0.001$, such that anxiety ratings when participants entered the lab were lower (M=35.20, SD=9.44) than anxiety ratings after completing the MA problems under high pressure (M=40.50, SD=11.16).

To determine if there were differences in pressure ratings between individuals who were high and low in math anxiety, a repeated measures ANCOVA was run in which pressure was treated as a within-subjects variable and math anxiety was treated as a continuous between subjects variable. State anxiety ratings were treated as the dependent variable. Overall, there was no main effect of pressure ($p > 0.05$). There was a main effect of math anxiety: $F(1, 80) = 10.51$, *p*=0.002, such that math anxious individuals reported higher state anxiety overall than low math anxious individuals. There was also a significant interaction between pressure ratings and math anxiety: F(1,80)=4.61, *p*=0.035, with individuals who were high math anxious increasing their state anxiety from low pressure (M=38.50, SD=9.32) to high pressure (M=44.88, SD=11.18), and individuals who were low math anxious not significantly increasing their state anxiety from low pressure (M=31.55, SD=8.15) to high pressure (M=35.90, SD=9.38). The means and standard deviations reported here are based on a median split of math anxiety.

To determine if there were differences in pressure ratings between individuals who were high and low WM, a repeated measures ANCOVA was run in which pressure was treated as a within-subjects variable and WM was treated as a continuous between subjects variable. State anxiety ratings were treated as the dependent variable. Overall, there was a main effect of pressure: F (1, 80) =11.65, *p*=0.001, but there was no main effect of WM (*p*>0.05) and no significant interaction between pressure and WM (*p*>0.05). There were no differences in the way that individuals who were high and low in WM rated their anxiety before low or after high pressure.

Lastly, we looked at whether there was an interactive effects on pressure ratings between pressure, math anxiety, and individual differences in WM. To test this, a repeated measures ANCOVA was run in which pressure was treated as a within-subjects variable and math anxiety and WM were treated as continuous between subjects variables. State anxiety ratings were treated as the dependent variable. The 2-way interaction between pressure and math anxiety was significant: F (1, 78) =4.16, *p*=0.045, with high math anxious individuals significantly increasing their pressure ratings and low math anxious individuals showing increases but not significantly so. All other main effects, 2-way interactions, and the 3-way interaction were not significant (p>0.05).

Modular Arithmetic (MA) Performance: Math Anxiety, Pressure, and Cognitive Demand

To determine how math anxiety impacted accuracy on MA problems under low and high pressure, a repeated measures ANCOVA was run in which cognitive demand of the problems and pressure were treated as within-subjects variables, and math anxiety was treated as a continuous between subjects variable. MA accuracy served as the dependent variable. There was a significant main effect of math anxiety: F (1, 81) =6.95, p=0.010, with individuals who were higher in math anxiety showing worse accuracy overall than individuals who were lower in math anxiety. There was a significant two-way interaction of demand and math anxiety: F (1, 81) =5.15, p=0.026, such that low math anxious individuals had higher accuracy on high demand problems than high math anxious individuals. There was no difference in low demand accuracy between low and high math anxious participants. There was also a significant two-way interaction of pressure and demand: F (1, 81) =11.13, p=0.001. Accuracy on high demand problems decreased under pressure overall, whereas accuracy on low demand problems did not. Additionally, there was a significant three-way interaction between math anxiety, pressure, and demand: F (1, 81) =9.12, p=0.003. On high demand problems, high math anxious individuals had lower accuracy under low pressure than low math anxious individuals. High math anxious individual's accuracy on high demand problems did not significantly differ under high pressure. Low math anxious individuals showed declines in accuracy on high demand problems under high pressure. On low demand problems there were no differences in accuracy between high or low math anxious individuals under low pressure, however under high pressure high math anxious individuals show lower accuracy on low demand problems than low math anxious individuals (Figure 1 and Table 1).

Figure 1. (Exp. 1) Modular arithmetic (MA) accuracy for low and high cognitively demanding problems under the low and high pressure conditions as a function of math anxiety

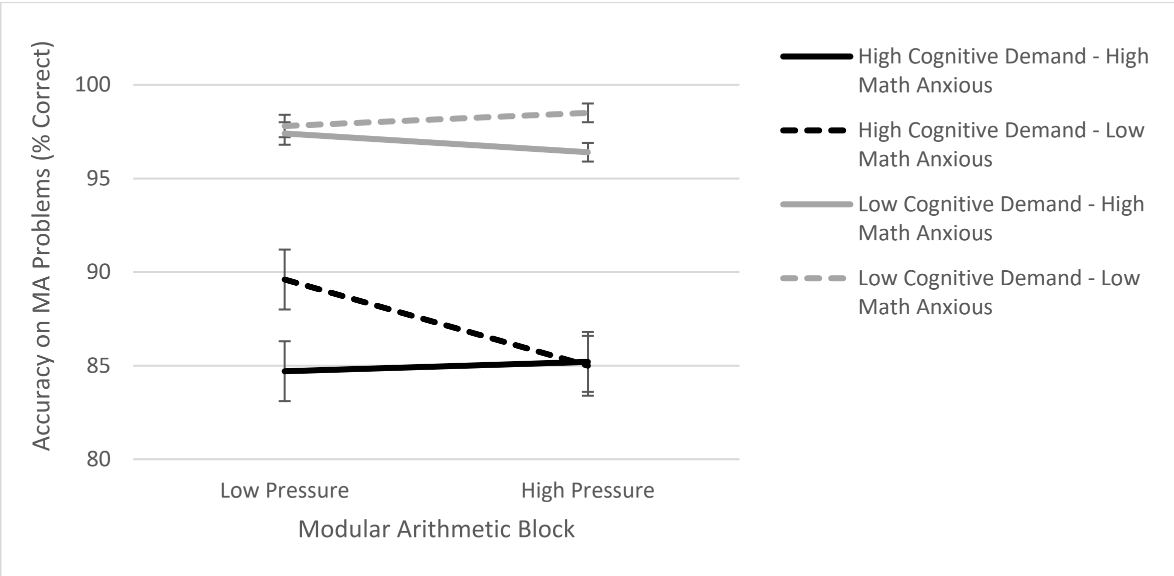


Table 1. (Exp. 1) Descriptive statistics for modular arithmetic accuracy (MA) for problems of both low and high cognitive demand under low and high pressure for high and low math anxious individuals (based on a median split)

Math Anxiety	WM Demand	Time Point	Mean	S.E.
Low Math Anxiety	Low	Pre Pressure	97.8	0.6
		Post Pressure	98.5	0.5
	High	Pre Pressure	89.6	1.6
		Post Pressure	85	1.6
High Math Anxiety	Low	Pre Pressure	97.4	0.6
		Post Pressure	96.4	0.5
	High	Pre Pressure	84.7	1.6
		Post Pressure	85.2	1.6

To rule out these effects being driven by either baseline differences in STAI or differential changes in STAI ratings across the pressure manipulation, the same ANCOVA was run with either the baseline STAI rating or the difference score in STAI rating from low pressure to high pressure added as a covariate. Each of the relationships described above remained significant when controlling for either STAI baseline or changes in STAI, and no main effects or interactions involving either the baseline STAI or the changes in STAI ratings from low pressure to high pressure reached significance.

To determine whether the declines in performance were driven by a speed/accuracy trade-off, a repeated measures ANCOVA with pressure and demand as within-subjects variables and math anxiety as a continuous between subjects variable was run with reaction time as a dependent variable. There was a main effect of demand, with faster reaction time on lower demand problems: $F(1, 81) = 13.52$, $p < 0.001$. All other main effects, two-way interactions, and the three-way interaction were not significant ($p > 0.05$). This suggests the effects of math anxiety and pressure on MA accuracy were not driven by a speed/accuracy trade-off.

Modular Arithmetic (MA) Performance: Math Anxiety, WM, and Pressure

Previous research has shown that there are differences in high demand MA accuracy for those individuals who are high and low WM when under low pressure and high pressure (Beilock & Carr, 2005). The data collected for this study replicate those findings and can be found in Sattizahn et al. (2016). Due to differences in MA performance for those individuals who are high and low in WM when under high or low pressure, I tested whether individual differences in WM interacted with math anxiety and pressure to affect performance. As there were a low number of subjects, I tested performance on low cognitive demand problems and high cognitive demand problems separately.

To determine how math anxiety, an individual's WM capacity, and pressure impacted accuracy on only low demand problems, a repeated measures ANCOVA was run in which pressure was treated as within-subjects variable, and math anxiety and WM scores were treated as continuous between subjects variables. Low demand accuracy was treated as the dependent variable. No significant main effects or interactions were found (p>0.05).

An additional repeated measures ANCOVA was run to determine whether math anxiety, WM, and pressure interacted to affect reaction times on low demand problems. Pressure was treated as a within-subjects variable, while math anxiety and WM were treated as continuous between subjects variables. Low demand reaction time was treated as the dependent variable. Again, no significant main effects or interactions were found (p>0.05).

I next looked at how accuracy on high demand problems was associated with math anxiety, individual differences in WM, and pressure. A repeated measures ANCOVA was run in which pressure was treated as a within-subjects variable and math anxiety and WM were treated as continuous between subjects variables. High demand accuracy was the dependent variable. There was a main effect of WM: F (1, 79) =5.73, p=0.019, with high WM individuals having higher accuracy on high demand problems overall than low WM individuals. There was also a main effect of math anxiety: F (1, 79) =8.38, p=0.005. Highly math anxious participants exhibited lower accuracy on high demand problems than low math anxious participants. The two-way interaction of WM and math anxiety was also significant: F (1, 77) =5.45, p=0.022. Low math anxious participants demonstrated higher accuracy on high demand problems if they were high in WM as compared to low WM participants who were low math anxious. For high math anxious individuals, there were no differences in accuracy on high demand problems between high and low WM participants (Figure 2 and Table 2).

Figure 2. (Exp. 1) Modular arithmetic (MA) accuracy for high cognitively demanding problems as a function of math anxiety and working memory

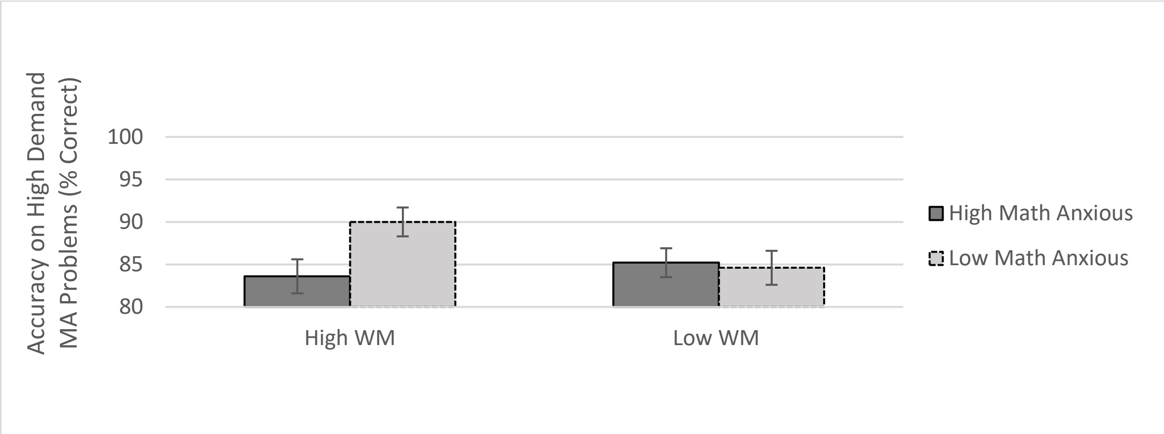


Table 2: (Exp. 1) Descriptive statistics for modular arithmetic (MA) accuracy for problems of high cognitive demand for high and low math anxious individuals and high and low WM individuals (based on a median split)

Math Anxiety	WM Capacity	Mean	S.E.
Low Math Anxiety	Low	84.6	2
	High	90	1.7
High Math Anxiety	Low	85.2	1.7
	High	83.6	2

The three-way interaction of WM, math anxiety, and pressure was not significant. However, the visualization of the three-way interaction shows a trend that is in line with previous research. Low math anxious participants showed declines in accuracy under pressure if they were high WM. Low math anxious participants who were low in WM did not show declines in accuracy from low pressure to high pressure. High math anxious participants of both low and high WM did not show declines in accuracy from low pressure to high pressure. Overall, the drop in high demand accuracy under pressure that has been demonstrated in previous research

(Beilock & Carr, 2005; Sattizahn et al., 2016) appears to be driven by low math anxious, high WM individuals, though this result was not significant (Figure 3 and Table 3).

Figure 3. (Exp. 1) Modular arithmetic (MA) accuracy for high cognitively demanding problems under the low and high pressure conditions as a function of math anxiety and working memory

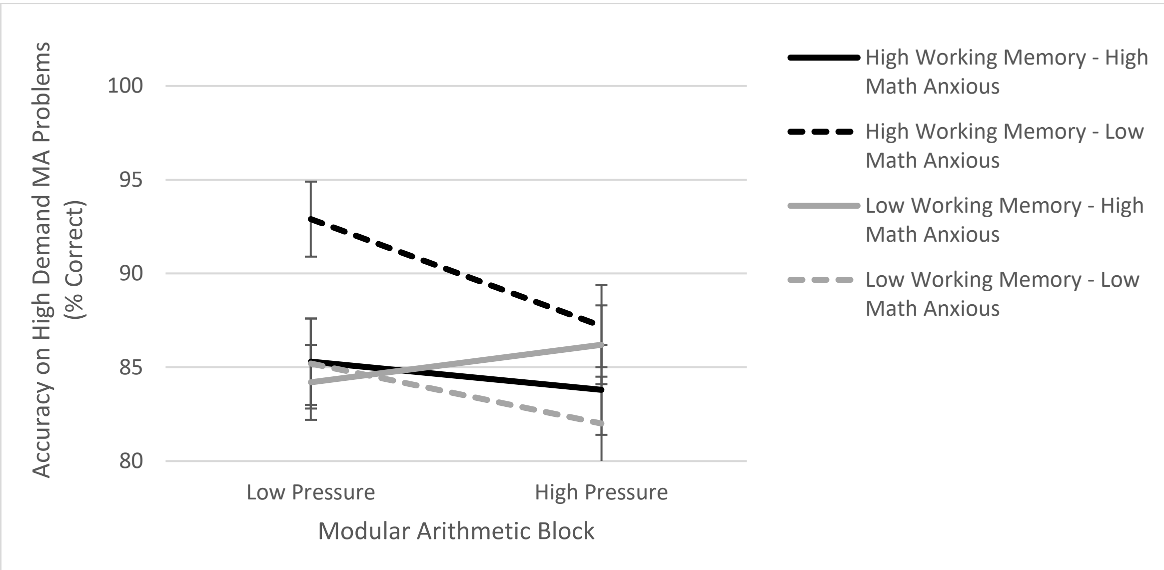


Table 3: (Exp. 1) Descriptive statistics for modular arithmetic (MA) accuracy for problems of high cognitive demand under low and high pressure for high and low math anxious individuals and high and low WM individuals (based on a median split)

Math Anxiety	WM Capacity	Time Point	Mean	S.E.
Low Math Anxiety	Low	Pre Pressure	85.2	2.4
		Post Pressure	82.0	2.5
	High	Pre Pressure	92.9	2.0
		Post Pressure	87.2	2.2
High Math Anxiety	Low	Pre Pressure	84.2	2.0
		Post Pressure	86.2	2.1
	High	Pre Pressure	85.3	2.3
		Post Pressure	83.8	2.4

I next examined whether the relation between high demand accuracy and math anxiety, WM, and pressure could be explained through a speed/accuracy trade off by testing their relation to MA reaction times. A repeated measures ANCOVA was run with pressure as a within-subjects variable, and WM and math anxiety as between subjects continuous variables. Reaction time on high demand problems served as the dependent variable. No significant main effects or interactions were found (*p*>0.05).

Modular Arithmetic (MA) Performance: State Anxiety, Math Anxiety, WM and Pressure

State anxiety was measured in participants twice: once before they began any math problems (whereby they had to learn a new form of math, which may be particularly stressful for highly math anxious individuals) and a second time after they finished the second block of math problems (whereby the pressure was increased through the pressure paradigm described above). As the first measure of state anxiety was taken before any math was completed, it doesn't shed light on how individual's state anxiety levels may be related to their math performance on this first block of problems, as state anxiety levels may have changed once participants began completing the math problems, particularly for highly math anxious individuals. As such, it is only possible to relate state anxiety following the second block of problems to math performance on the second block of problems.

To determine how low demand accuracy under pressure may be related to WM, math anxiety and state anxiety, a univariate ANOVA was run in which a median split of WM, a median split of math anxiety, and a median split of STAI-S that was reported following the pressure block were used as an independent variables. Accuracy on low demand problems served as the dependent variable. There was a significant main effect of math anxiety: $F(1, 73) = 7.09$, $p=0.010$, whereby high math anxious individuals showed lower accuracy on low demand problems than low math anxious individuals. All other main effects and interactions were not significant.

The effects of WM, math anxiety, and STAI-S reported following the pressure block were then related to reaction time on low demand problems completed under pressure. A similar univariate ANOVA as described previously was used, with low demand reaction time on the second block serving as the dependent variable. There was a main effect of WM: $F(1, 73) = 9.10$, $p<0.001$, with high WM individuals showing faster reaction times than low WM individuals. The two-way interaction of math anxiety and state anxiety approached significance: $F(1, 73) = 3.58$, $p=0.063$. Low math anxious individuals who reported low state anxiety showed the fastest reactions times. Low math anxious individuals who reported high state anxiety showed reaction times that were similar to high math anxious individuals with either high or low reported state anxiety.

To determine how reported state anxiety as measured by the STAI-S related to high demand accuracy for MA problems completed under pressure, a univariate ANOVA was run in which WM based on a median split, math anxiety based on a median split, and a median split of STAI-S reported after block 2 were each entered as independent variables. High demand MA accuracy on block 2 problems served as the dependent variable. The two-way interaction of math anxiety and state anxiety was significant: $F(1, 73) = 5.24$, $p=0.025$. Independent of WM, high math anxious individuals who had low state anxiety showed higher accuracy on high demand problems than high math anxious individuals who reported high state anxiety. Low math anxious individuals with low state anxiety showed lower accuracy on high demand problems than low math anxious individuals with high state anxiety. All other main effects and interactions were not significant.

To determine if these effects were caused by a speed/accuracy trade-off, a univariate ANOVA was run in which a median split of WM, a median split of math anxiety, and a median split of STAI-S reported after block 2 each served as independent variables. Reaction time on high demand problems served as the dependent variable. There was a main effect of state anxiety: $F(1, 73)= 3.97$, $p=0.050$, such that participants who reported higher state anxiety had lower reaction times than individuals with lower state anxiety. The two-way interaction of math anxiety and state anxiety was also significant: $F(1, 73)= 6.09$, $p=0.016$. Individuals who were low in math anxiety and low in state anxiety showed faster reaction times than individuals who were low in math anxiety and high in state anxiety. Individuals who were high in math anxiety and high in state anxiety showed faster reactions times than those who were high in math anxiety and low in state anxiety. These results indicate that the interaction of math anxiety and reported state anxiety on MA performance of high demand problems was due to a speed accuracy trade-off. That is, the improvements in accuracy for individuals who were low in math anxiety and high in state anxiety and for those individuals who were high in math anxiety and low in state anxiety were due to changes in reaction time.

Discussion

Highly math anxious undergraduate adults showed increased state anxiety in a low pressure situation as compared to low math anxious adults. Additionally, these highly math anxious individuals showed further increases in their state anxiety following a pressure induction, whereas low math anxious individuals did not. After experiencing a pressure situation in which individuals need to perform cognitively demanding math problems, highly math anxious adults show higher ratings of state anxiety than low math anxious adults. This may be due to the nature of the task at hand. That is, they are required to perform difficult math problems, surrounding which they have great trait anxiety, and their performance ultimately affects not only the compensation they receive from the experiment but seemingly also the compensation of another individual (i.e. the situational pressure is high).

In terms of math performance, highly math anxious individuals performed lower on cognitively demanding math problems in a low pressure scenario as compared to low math anxious individuals, and their math accuracy did not significantly decline under pressure. There was no compound effect of math anxiety and pressure induced state anxiety on math performance. Low math anxious individuals experienced a decline in performance on cognitively demanding math problems when experiencing pressure to perform, and this decline in accuracy dropped their performance to a similar level of highly math anxious individuals when they were not under pressure. Ultimately, the behavioral effect of high trait math anxiety was similar to the behavioral effect of pressure in low math anxious adults. This is likely due to the effect of anxiety on limited-capacity WM resources. For low cognitive demand problems, high math anxious participants under pressure showed declines in performance as compared to low math anxious participants. One explanation for this may be that a compound effect of trait and state anxiety is being observed for low demand problems that don't require a limited amount of WM resources to arrive at an answer. The compound effect of trait math anxiety and situational state anxiety is so great that math performance based on procedural recall becomes disrupted.

When taking into account differences in WM capacity, results show that adults who were low in math anxiety and high in WM showed the highest accuracy overall on high cognitive demand problems, regardless of pressure. Individuals who were low in math anxiety and low in WM showed similar high demand accuracy to individuals who were high in math anxiety and were either high or low in WM. Despite the lack of significance likely due to low power and high variance, the WM results observed across the low pressure and pressure condition seem to mirror those found in Beilock and Carr (2005). That is, it is the high WM, low math anxious individuals who drive the drop in high demand accuracy under pressure. Our low WM participants, regardless of math anxious, showed low math accuracy on high demand problems in the low pressure condition that did not change in the high pressure condition. Beilock and Carr (2005) found that low WM individuals showed lower accuracy on high demand problems regardless of pressure, which is in line with our results. For our high WM individuals, high math anxiety was associated with declines in math accuracy on high demand problems in the low pressure condition as compared to our high WM, low math anxious participants, and these effects were not exacerbated by situational pressure. Our high WM individuals who were low math anxious showed the highest math accuracy on high demand problems in the low pressure condition, and situational anxiety resulted in a decline in math accuracy for these individuals. These results suggest that for individuals with high WM, the behavioral effect of high trait math anxiety is similar to the behavioral effect of pressure in low math anxious individuals, and this effect is likely due to the effects of anxiety on available WM resources.

It was only possible to study the effects of reported levels of state anxiety on math performance in the second block of MA problems as no state anxiety measure was taken directly after the first block of problems before pressure was induced situationally. At face value it appeared as though there was a significant compound effect of math trait anxiety and state anxiety on high demand accuracy, whereby high math anxious individuals who experienced high state anxiety showed poor math performance as did low math anxious individuals who experienced low state anxiety. However, upon further inspection these declines in accuracy were due to a speed/accuracy trade-off. As such, it remains unclear how reported state anxiety interacts with math trait anxiety under pressure in undergraduate adults. It may be that a larger sample size would shed light on this interaction. It is possible that a measure of reported pressure (rather than state anxiety as measured by the STAI-S) would more accurately tease apart this relationship. This measure was not collected in this particular experiment, and future studies would benefit from adding this measure into their design.

The failure to observe a decline in math performance under pressure for high math anxious individuals may be due to the fact that the low pressure scenario in this study was not in fact experienced as low pressure for high math anxious individuals. They are in a testing scenario in a laboratory, and they are performing math problems that inherently make them feel anxious. It is possible that the lower math accuracy on high demand problems in the first block of MA problems was due to the anxiety that any testing situation induces in math anxious individuals. Future studies that attempt to examine the relationship between math anxiety and state anxiety ought to establish a truly low pressure environment, which might include the removal of any form of 'grading' or might involve providing positive feedback for participants that notifies them they are performing similarly well to other participants who have completed similar problems.

EXPERIMENT 2

I now look to a different population to determine how trait math anxiety and state anxiety interact to affect math performance. Not only does math anxiety affect the math performance of adults, but it affects the math performance of children as well. Importantly, children's own math anxiety and parent's math anxiety have been separately shown to affect children's math performance. To determine how situational anxiety may relate to math anxiety and math performance, I look to a parent/child interaction designed to simulate homework. Importantly, this reflects a real-world situation that is encountered at the beginning stages of elementary school and may induce situational anxiety for parents or children or both. I aimed to determine if children and parents experience increased state anxiety following a parent/child math interaction where the pressure to perform is high as compared an interaction where the pressure to perform is low. I also aimed to test whether this varies as a function of child math anxiety or parent math anxiety. Importantly, in the current study I aimed to induce a low pressure condition that truly alleviates the pressure individuals feel to perform well (see discussion from study 1). I ask separately how math anxiety and situational anxiety of both the child and the parent may interact with the WM of the child to impact children's math performance. Lastly, I aimed to determine if a pressure-inducing or a low pressure interaction differentially affect parent's math performance following the interaction, and if this performance is further qualified by parent's math anxiety and reported levels of state anxiety.

In order to test this, participants (mother and child) completed a math interaction where the child solved math problems and the mother helped in solving the math problems. Half of the participants completed the math interaction in a pressure situation, while the other half completed the math interaction in a low pressure situation. Following the math task, state anxiety was measured in both mothers and children. Math anxiety in both the parent and the child was measured prior to the interaction. Children's WM capacity was measured prior to the interaction. Following the interaction, children's math performance was measured on a math achievement measure. Additionally, parent's math performance on high and low cognitively demanding math problems was also measured. The interactions were videotaped.

I hypothesized that parents/children who completed the math interaction under pressure would experience greater state anxiety following the interaction than those parents/children who completed the math interaction without pressure. I hypothesized that children who completed the math interaction with their parents under pressure would perform worse on the math interaction task than those children who completed the math interaction in a low pressure condition. Due to the fact that parents were helping their child solve the math problems, the math performance during the interaction does not stand as a true measure of children's math performance. Therefore, I aimed to test the effects of children's math/state anxiety and parent's math/state anxiety on children's math performance on a math achievement measure following the interaction. When examining children's math and state anxiety, I predicted that children's math anxiety and state anxiety would interact to affect math performance, and this would depend on children's WM capacity. That is, if children were high in WM and were identified as high math anxious, high levels of reported state anxiety would be associated with declines in performance. If children were high in WM and were identified as low math anxious, high state levels of anxiety may not in fact be debilitative but may instead induce higher levels of math performance. For individuals who are low in WM, it is possible that the compound effects of high trait and state anxiety would be even greater at inducing declines in math performance as low WM show lower levels of math performance overall, which may be due to lower math ability or to lower motivation to perform well. Alternatively, it is possible that high levels of state anxiety would be associated with higher levels of math performance as they induce arousal/motivation that may positively impact the performance of low WM children. When examining parent's math and state anxiety, I predicted that parent's math anxiety and state anxiety would interact in a similar way to that of children's math and state anxiety to affect math performance, which would again depend on children's WM capacity. Additionally, if the pressure manipulation was successful, I hypothesized that parents who experienced the math interaction under pressure would show subsequent declines in their own math performance on those problems that tax WM as compared to the low pressure condition (if the low pressure condition was indeed experienced as low pressure). Those parents who were high math anxious under pressure would show the greatest declines in math problems that were cognitively demanding.

Methods

Participants

Mothers and their children in kindergarten, first, and second grade were recruited for participation (age: 6-8 y/o, M: 7.15, SD: 0.43, Females: 53, Males: 50) through a pool of participants collected from prescreen surveys that were distributed to elementary schools in the Chicagoland area and through the University of Chicago Infant Database. A total of 103 pairs of individuals were brought into the lab for one testing session (approximately 1 hr. and 15 min.) after completing the initial prescreen survey. Participants were reimbursed either $20 (database participants) or $30 (survey participants) for their participation. This study was approved by the Institutional Review Board at the University of Chicago.

Materials

Questionnaires: Prior to arriving in the lab, the mother participants completed a battery of questionnaires that included a math anxiety questionnaire (sMARS; Alexander & Martray, 1989). Once in the lab following the math interaction, mothers completed an anxiety questionnaire (STAI-S: Spielberger & Gorsuch, 1983), questions relating to pressure (see Beilock & DeCaro, 2007), and additional questionnaires relating to parent's attitudes and beliefs surrounding their children's current and future math ability. In the lab children completed a math anxiety questionnaire prior to the math interaction, an anxiety question to measure state anxiety following the math interaction, a modified pressure questionnaire to measure pressure following the interaction, and additional questionnaires regarding their attitudes and beliefs toward math and reading. Questionnaires regarding attitudes and beliefs of the parents and children were not analyzed in the current study.

Working Memory Measures: The children completed both a forward letter span task and a backward letter span task prior to the math interaction to determine their WM capacity. In the forward letter span task, a researcher said letters out loud to the child, after which the child repeated the letters to the researcher. The researcher said one letter per second when administering the task. Within each run, there were two trials. A child moved onto the next run if she or he got at least one out of the two trials correct. If a child got both trials incorrect, they did not advance. The number of letters a child had to repeat in each run increased by one letter. The backward span task operated similarly, except instead of repeating the letters to the researcher verbatim, the child would say the letters back to the researcher in the reverse order. For example, if the researcher said "B, L, K, T" out loud to the child, the child would have to say "T, K, L, B" back to the researcher in order to get the trial correct. Children's WM capacity was computed as a sum of the total number of runs completed correctly in both the forward and backward letter span task.

Children's Baseline Math Task: Prior to completing the math interaction together with their mom, children answered 6 addition and subtraction word problems that were read aloud to them by the experimenter. The children were not given any paper or pencil to work on the problems and were asked provide their response verbally. Their accuracy on this task served as a baseline measure of math performance to establish differences in math ability prior to the math interaction with their mothers. The baseline math task is included in Appendix A.

Parent/Child Math Interaction: The parent/child math interaction lasted for exactly ten minutes. During this interaction, mothers and children worked together to solve math problems related to a story they read together. Prior to beginning the problems, mothers and their children watched a video in which a male experimenter explained to them what they would be working on together. For half of the participants, both the parent and the child received instructions that they were to view this task similar to math homework. They were told their child would be graded on the problems and feedback would be given that would compare their performance to others. They were also told that most students who complete the task finish all of the problems given to them, when in reality the pilot data showed that children answer about 30-35% of the questions. The answers to the problems were not provided. This was the ‘pressure’ group. For the other half of the participants they received instructions to work on some math problems together and finish as many as they could. They were told to go at their own pace and were told not to worry about how many problems they completed. They were told they were there to practice math together. The answers to the problems were also provided at the bottom of the page. This was the ‘low pressure’ group. All of the participants were told they will be videotaped in order to help train future RAs and to have an idea of what occurred during the interaction. All of the participants were also told they would have ten minutes to work on the problems together. The instructions for both the pressure and the low pressure group are included in Appendix B. The problems that the parent/child worked on are included in Appendix C.

Modular Arithmetic: Parents completed one block of MA following the math interaction that is similar to the MA described in experiment 1. The MA task began with a training session that explained MA and how to solve MA problems. The participant then completed 8 practice problems of both high and low cognitive demand. After the practice set the subject completed one block of 24 MA problems that were presented horizontally. Half of the problems were of high cognitive demand and the second half were of low cognitive demand. Accuracy and reaction time were recorded in both blocks of problems. The MA performance served both as a measure of parent's math ability and also as a measure of WM decrements following the math interaction.

Woodcock-Johnson III Applied Problems subset: Following the math task the children completed the Woodcock-Johnson II Applied Problems subtest (Woodcock, McGrew & Mather, 2001). The Woodcock Johnson battery was used as it nationally-normed and assesses academic achievement across individuals of a very wide age range (2-90 y/o). For this measure, children are presented with word-problems that are math related that increase in difficulty as the child progresses. The initial problems establish basal performance, which requires six problems in a row correct, and the child continues until she or her reaches ceiling, which is defined as six items in a row incorrect while also finishing all of the problems presented on that page.

Procedure

Upon arrival into the lab, mothers were given a consent form and children were walked through a verbal assent script. After agreeing to participate, mothers and children were separated into different rooms. The child completed the forward and backward letter span tasks, the baseline math task and the math anxiety questionnaire. During this time the mother completed an executive functioning task. After this the mother and the child were brought together for the math interaction. For the math interaction, participants were assigned to one of two conditions: a low pressure and a high pressure condition. Importantly, the experimenters were blind to the condition.

Following the math interaction, the mother and child were separated. The mothers completed an anxiety questionnaire (STAI-S), a pressure questionnaire, and a questionnaire about their attitudes and expectations of their child's math ability. This was followed by the MA task, which served as a measure for math performance in parents and a proxy measure for WM. Mothers finished the experiment answering additional questionnaires.

Following the interaction an experimenter administered to the children an anxiety question, a pressure questionnaire, and a questionnaire about their attitudes toward math and reading. The children were then administered the Woodcock Johnson applied problems (form B) as a measure of their math performance. Children finished the experiment answering additional surveys.

After the mothers and children each finished their portion of the experiment, the mothers were debriefed and told that if they were in the condition where they were told they would be graded and evaluated, that this was in fact not the case. They were told that the experiment tested ideas regarding pressure when working together over math, similar to a homework setting. They were told that in order to simulate homework, it had to seem as though they would in fact be graded and evaluated. After debriefing, mothers were paid either $20 or $30 for their participation and the children received a small toy.

Results

Data Transformations

Two sets of individuals did not complete the math interaction, and therefore data were not analyzed for these subjects. One pair of participants was excluded from the analyses due to the duress the child felt after the interaction. An additional pair did not complete the interaction sufficiently (i.e. did not get any questions correct and did not show any work for solving the problems), and those data were therefore excluded from the analyses. Lastly, in the parent MA task, one participant scored an average accuracy that was at chance (50%) and her response times were far beyond the realm of possible response times for high demand problems (i.e. an average of 835 ms for this participant compared to the sample average of 10,504.72 ms). Therefore, data collected from this participant and her child were excluded from analyses. After excluding these 5 participants, data was analyzed for a total of 98 subjects, of which 48 pairs of participants completed the pressure condition (F: 24, M: 24) and 50 pairs of participants completed the low pressure condition (F: 25, M: 25).

In the overall sample (pressure and low pressure conditions combined), parent math anxiety ratings were in line with published norms (M=31.42, SD=20.93, range=0-100; Alexander & Martray, 1989: M= 31, SD=16). Parent math anxiety was moderately positively skewed and was therefore square root transformed, which resulted in a normal distribution of parent math anxiety. Therefore, the transformed data were used in the following analyses. Parent state anxiety was measured by the STAI-S was positively skewed (M= 31.05, SD= 8.12, range: 20-56). A log transformation resulted in a normal distribution, and therefore log transformed values are used for all analyses involving parent STAI-S.

Children's math anxiety was normally distributed across the entire sample (M= 10.19, SD=11.56, range= 18-66). The children's WM composite, which consisted of a sum of the forward and backward span tasks, was positively skewed (M=8.73, SD= 2.52, range= 2-22) and a square root transformation resulted in a normal distribution. Therefore, all further analyses regarding children's WM utilized the transformed data. Children's baseline math performance was negatively skewed (M= 4.44, SD= 1.78, range= 0-6) as the questions were relatively easy for the children to solve. No data transformation resulted in a normal distribution and therefore the raw data were used in the following analyses. For the math interaction task, the total number of questions answered correctly (M= 5.73, SD= 3.03, range= 0-15) and the total number of questions attempted (M= 6.11, SD= 3.23, range= 2-15) were positively skewed due to the difficulty of the problems and the short time limit allotted to solve the problems. No data transformation resulted in a normal distribution, and therefore raw data were used in analyses for the math interaction task. Children's W scores, which signify math performance on the Woodcock Johnson applied problems, were normally distributed within the entire sample (M= 468.53, SD= 25.33, range= 390-526).

Children's Math Anxiety: Preliminary Analyses

Math anxiety is demonstrated to be higher in females than in males (Dowker et al., 2016). Therefore, preliminary analyses were done to determine sex differences in math anxiety in our sample. In the overall sample, female children had marginally significantly higher math anxiety than male children: $t(96)= 1.85$, $p=0.068$ (Females: M= 42.33, SD= 10.65, Males: M= 38.06, SD= 12.14). The impact of this relation between children's math anxiety and the sex of the child on analyses pertaining to children's math performance following the pressure manipulation are discussed below.

The highest level of education completed by the primary caretaker (i.e. the parent who was tested in the lab) was negatively related to child math anxiety ($r= -0.38$, $p<0.001$). Parents whose children were high in math anxiety reported lower education levels than those parents whose children were low in math anxiety. Parent's highest level of education completed was significantly correlated with the number of math classes that parents took in their high school and college careers ($r= 0.265$, $p=0.009$). Despite this relation between education level and the total number of math classes taken, there was no relation between the total number of math classes taken by the parent and their children's math anxiety ($r= -0.074$, $p= 0.47$). Additionally, the family's annual gross income was significantly related to the parent's highest level of education completed, however the family's annual gross income was not significantly related to children's math anxiety. These results suggest that children's math anxiety is linked to the level of education completed by the parent.

Parent's Math Anxiety: Preliminary Analyses

As parent's math anxiety has been demonstrated to affect their children's math performance (Maloney et al., 2015), we sought to determine whether there was a direct link between parent's math anxiety and the math anxiety of their child. Parent math anxiety was not significantly correlated with children's math anxiety in the entire sample ($r=0.019$, $p=0.85$), within only females ($r= -0.076$, $p=0.60$) or within only males, ($r=0.11$, $p=0.45$). Additionally, there was no difference in parent math anxiety based on a median split between female children ($M= 30.77$, $SD= 21.66$) and male children ($M= 32.08$, $SD= 20.37$): $t(96)= -0.26$, $p= 0.80$. Importantly, these analyses suggest that there is no clear, direct relation between parent math anxiety and child math anxiety. As such, parent math anxiety and child math anxiety will be considered separately in analyses as possible trait anxieties that may affect math performance of children participants following the math interaction. Once again, due to the lack of differences in the relation between parent math anxiety and children's sex, the child's sex will not be used as a variable in the analyses examining the relation between parent math anxiety and children's math performance following the interaction.

Similar to math anxiety in children, the parent's highest level of education completed was negatively related to their own math anxiety ($r= -0.25$, $p=0.015$). The total number of math classes the parent had taken in high school and college showed a negative, marginally significant relation to parent's math anxiety ($r= -0.20$, $p=0.051$). Additionally, the family's annual gross income was also negatively related to parent math anxiety ($r= -0.27$, $p=0.008$). To determine how each of these factors contributed to parent math anxiety simultaneously, a linear regression was run in which all three of these factors were entered as independent variables and parent math anxiety served as the dependent variable. The overall model was significant: $F(3, 95)= 2.79$, $p=0.045$, with an adjusted R square value of 0.054. When controlling for each of the other two variables, annual gross income showed the greatest relation to parent math anxiety: $B= -0.22$, $p=0.11$. Education level was no longer significant ($p=0.75$) and neither was the total number of math classes taken ($p=0.41$). These results suggest that in adults, a strong predictor of parent math anxiety is the family's annual gross income.

Children's Working Memory: Preliminary Analyses

The overall sample showed no differences in composite WM scores between female children ($M= 8.9$, $SD= 1.93$) and male children ($M= 8.56$, $SD= 3.01$): $t(96)= 0.86$, $p=0.39$. Within the overall sample, children's WM scores were significantly negatively correlated with child math anxiety ($r= -0.34$, $p=0.001$) and parent math anxiety ($r= -0.25$, $p=0.013$). Additionally, children's WM was positively related to the parent's highest level of education completed ($r= 0.38$, $p<0.001$) and to the family's annual gross income ($r= 0.37$, $p<0.001$). To determine how the parent's education and the family's annual gross income relate to children's WM simultaneously, a linear regression was run in which parent's highest level of education completed and the family's annual gross income were entered as independent variables and children's WM served as the dependent variable. The overall model was significant: $F(2, 95)= 9.37$, $p<0.001$, with an adjusted R square value of 0.15. When statistically controlling for the family's annual gross income, the parent's highest level of education showed a marginal, positive relation to children's WM: $B= 0.22$, $p=0.083$. Additionally, when statistically controlling for the parent's highest level of education, the family's annual gross income also showed a marginal positive relation to children's WM: $B= 0.23$, $p=0.071$. These results suggest that both parent's education level and the family's annual gross income independently relate to children's WM capacity.

Baseline Math Performance

Preliminary analyses were performed on children's baseline math performance to determine which factors relate to children's math performance prior to any pressure manipulation. In the overall sample, there were no significant differences between females and males in baseline math performance: $t(96)= -0.057$, $p=0.96$ (Females: M= 4.43, SD= 1.79, Males: M= 4.45, SD= 1.77). Children's math anxiety was significantly negatively correlated with children's baseline math performance ($r= -0.20$, $p=0.029$). Despite the lack of relationship between parent math anxiety and children's math anxiety, parent math anxiety was also significantly negatively correlated with children's baseline math performance ($r= -0.203$, $p=0.044$). Baseline math performance was positively correlated with children's WM ($r= 0.47$, $p<0.001$), the parent's highest level of education completed ($r= 0.29$, $p=0.004$), and the family's annual gross income ($r= 0.29$, $p=0.004$). The number of math classes taken by the parent in high school and college were not related to children's baseline math performance ($r= 0.008$, $p=0.94$).

To determine how both parent math anxiety and child math anxiety impacted children's baseline math performance, both parent math anxiety and child math anxiety were simultaneously entered as independent variables into a linear regression while baseline math performance served as the dependent variable. The overall model was significant: $F(2, 97)= 4.60$, $p=0.012$, with an adjusted R square value of 0.069. When controlling for parent anxiety, child math anxiety was negatively associated with baseline performance: $B=-0.22$, $p=0.030$. When controlling for child math anxiety, parent math anxiety was also negatively associated with baseline math performance: $B= -0.20$, $p=0.045$. These results lend further credence to examining both parent math anxiety and child math anxiety as separate trait anxiety variables in predicting child math performance.

To determine how baseline math performance was affected simultaneously by children's WM, the parent's highest level of education completed, and the family's annual gross income, each of these factors was entered as independent variables in a linear regression in which children's baseline math performance served as the dependent variable. The overall model was significant: $F(3, 95)= 10.36$, $p<0.001$, with an adjusted R square value of 0.23. While statistically controlling for both parent's education level and the family's annual gross income, WM was highly significant in positively predicting the children's baseline math performance: $B= 0.42$, $p<0.001$. When controlling for the other two variables, the parent's highest level of education completed ($p=0.40$) and the family's annual gross income ($p=0.56$) were no longer significant in predicting children's baseline math performance. These results suggest that children's math performance is highly related to their WM capacity, which is supported in previous literature (McLean & Hitch, 1999; Holmes & Adams, 2006; Rasmussen & Bisanz, 2005; Gathercole & Pickering, 2000).

Pressure Manipulation: Preliminary Analyses

Independent samples t-tests were run to determine if there were any differences in factors that may impact how an individual responded to the math interaction. There were no differences between the pressure and low pressure condition in parent's math anxiety: $t(96)= -0.37$, $p=0.71$ (pressure: $M= 30.05$, $SD= 19.02$, low pressure: $M= 32.85$, $SD= 22.86$), the primary caretaker's highest level of education completed: $t(96)= 1.20$, $p=0.23$ (pressure: $M= 4.79$, $SD= 1.92$, low pressure: $M= 5.24$, $SD= 1.78$), and the family's annual gross income: $t(94)$: 1.95, $p=0.054$ (pressure: $M=4.76$, $SD=2.98$, low pressure: $M=6.06$, $SD=3.48$)(though there was a marginally significant difference in this variable whereby the pressure condition had lower annual gross income than the low pressure condition). Additionally, there were no differences between the pressure and low pressure condition in children's age: t(96)= -0.50, p= 0.61 (pressure: M=7.20, SD= 0.39, low pressure: M= 7.15, SD= 0.42), children's math anxiety: t(96)= -0.67, p=0.50 (pressure: M= 41.00, SD= 12.48, low pressure: M= 39.42, SD= 10.67), children's baseline math performance: t(96)= 0.69, p=0.49 (pressure: M= 4.31, SD= 1.77, low pressure: M= 4.56, SD= 1.78), and children's WM scores: t(96)= -1.12, p=0.31 (pressure: M= 9.0, SD= 2.77, low pressure: M= 8.48, SD= 2.26).

As reported above, female children reported higher math anxiety than male children within our sample. Importantly, there were no differences in the number of female children and male children in the pressure (F: 24, M: 24) and low pressure condition (F: 25, M: 25). However, to establish that these differences in math anxiety between the sexes were not different between the pressure and low pressure condition, an independent samples t-test was run within both the pressure and low pressure condition that compared children's math anxiety between females and males. Within the pressure and low pressure condition, a similar trend was found such that female children had higher math anxiety, though the difference between females and males in math anxiety was not significant in either condition. There was no significant difference in female child math anxiety between the pressure and low pressure conditions: t(47)= -0.48, p= 0.63 (pressure: M= 43.08, SD= 11.35, low pressure: M= 41.60, SD= 10.11). There was also no significant difference in male child math anxiety between the pressure and low pressure conditions: t(47)= -0.48, p= 0.63 (pressure: M= 38.92, SD= 13.43, low pressure: M= 37.24, SD= 10.97). As such, the child's sex will not be used as a variable in the analyses examining child math anxiety.

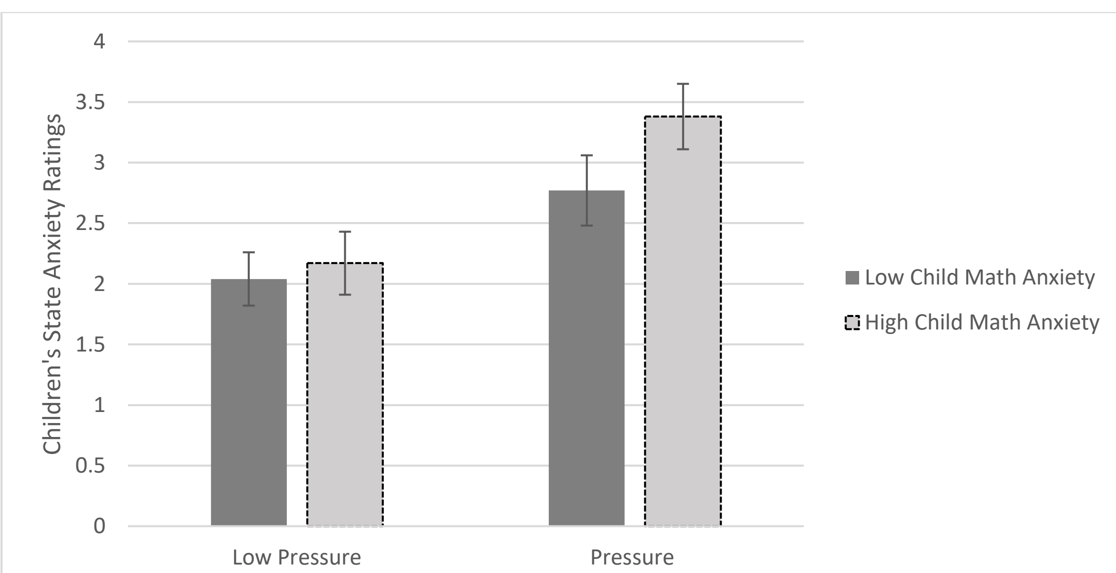
Anxiety Ratings and Pressure Manipulation: Children

To determine whether the pressure manipulation worked in children, an independent samples t-test was run that compared children's rating of state anxiety as measured by a one item anxiety question. Those children in the pressure condition reported significantly greater state anxiety than those children in the low pressure condition: $t(96)= -3.84$, $p<0.001$ (pressure: $M= 3.10$, $SD= 1.40$, low pressure: $M= 2.10$, $SD= 1.18$). There were no differences in pressure ratings that were measured via pressure questions modified for young children. The lack of a difference in the ratings of pressure as reported by children in the pressure and low pressure condition is not surprising as the majority of the child participants did not understand what pressure meant (as observed and reported anecdotally by two separate experimenters).

I next sought to determine how children's math anxiety was related to perceived pressure. Within the entire sample, a marginally significant positive correlation was found between child math anxiety and children's reported state anxiety ($r= 0.19$, $p=0.057$). Children with high math anxiety (based on a median split) showed a trend for greater state anxiety following the pressure interaction than children with low math anxiety: $t(96)= -1.62$, $p=0.11$ (high math anxiety: $M= 2.88$, $SD= 1.45$, low math anxiety: $M= 2.37$, $SD= 1.29$), though the relationship was not significant. There were no differences in child state anxiety between parents with high math anxiety and low math anxiety ($p=0.89$) or between children who were high or low in WM ($p=0.66$). Additionally, in a univariate ANOVA in which children's math anxiety, parent's math anxiety, and children's WM were treated as independent variables, and children's reported state anxiety served as the dependent variable, all two-way interactions and the three-way interaction of child math anxiety, parent math anxiety, and children's WM were not significant. That is to say, the best predictor of children's reported state anxiety was children's math anxiety.

When further broken down by pressure and low pressure, there were no differences in state anxiety between children who were high math anxious and low math anxious (based on a median split) in the low pressure condition: $t(48)= -0.40$, $p=0.69$ (high math anxiety: $M= 2.17$, $SD= 1.27$, low math anxiety: $M= 2.04$, $SD= 1.13$). These results suggest that the low pressure condition was perceived to be low pressure by highly math anxious children. Within the pressure condition, there were no significant differences between state anxiety for those individuals who were highly math anxious and low math anxious (based on a median split), though highly math anxious children showed a trend of reporting higher state anxiety than low math anxious children: $t(46)= -1.53$, $p=0.13$ (high math anxiety: $M= 3.38$, $SD= 1.39$, low math anxiety: $M= 2.77$, $SD= 1.38$). Overall, the low math anxious children within the pressure condition rated higher state anxiety than both low and highly math anxious children within the low pressure condition, and the highly math anxious children within the pressure condition rated the highest state anxiety of each of the four conditions (Figure 4, means and standard deviations presented in the above text).

Figure 4. (Exp. 2) Subjective children's state anxiety ratings following the parent/child math interaction. The means depicted here are based on a median split of math anxiety.



There were no differences in state anxiety for children in the pressure condition or the low pressure condition based on parent math anxiety. There were also no differences in children's state anxiety for children in the pressure and low pressure condition based on children's WM scores. A univariate ANOVA was run in which pressure, children's math anxiety, parent's math anxiety, and children's WM served as independent variables and children's state anxiety served as the dependent variable. The two-way, three-way and four-way interactions of pressure, children's math anxiety, parent's math anxiety, and children's WM scores were not significant. These results suggest that the pressure condition worked to induce higher state anxiety in the children who were in the pressure condition, and these results were modified, though not significantly, by children's math anxiety levels, such that high math anxious children in the pressure condition demonstrated the highest reported state anxieties.

Anxiety Ratings and Pressure Manipulation: Parents

To determine whether the pressure manipulation was successful at inducing higher anxiety/pressure in parents following the parent/child math interaction, state anxiety as measured by the STAI-S completed after the interaction was compared between parents in the pressure and low pressure groups. There was a trend for parents within the pressure condition to report higher state anxiety ratings than those individuals within the low pressure condition as measured by the STAI-S: $t(96) = -1.42$, $p = 0.16$ (pressure: $M = 32.10$, $SD = 7.85$, low pressure: $M = 30.01$, $SD = 8.32$). Additionally, parents in the pressure group reported a trend that they felt more performance pressure in regard to supporting and helping their child to perform well on the set of math problems as compared to the low pressure group: $t(94.5) = -1.71$, $p = 0.090$ (pressure: $M = 4.34$, $SD = 1.93$, low pressure: $M = 3.72$, $SD = 1.65$). Although it's not significant, it is trending in the hypothesized direction. Additionally, parents in the pressure group indicated that they felt their child performed significantly less well on the math problems than those parents in the low pressure group: t(73.52)= 2.67 p=0.009 (pressure: M= 5.09, SD= 1.72, low pressure: M= 5.88, SD= 1.04). Overall, these data suggest that the manipulation was successful at inducing higher perceived anxiety/pressure in those parents in the pressure condition. It is likely that with further data collection and a higher number of subjects, these differences will become significant.

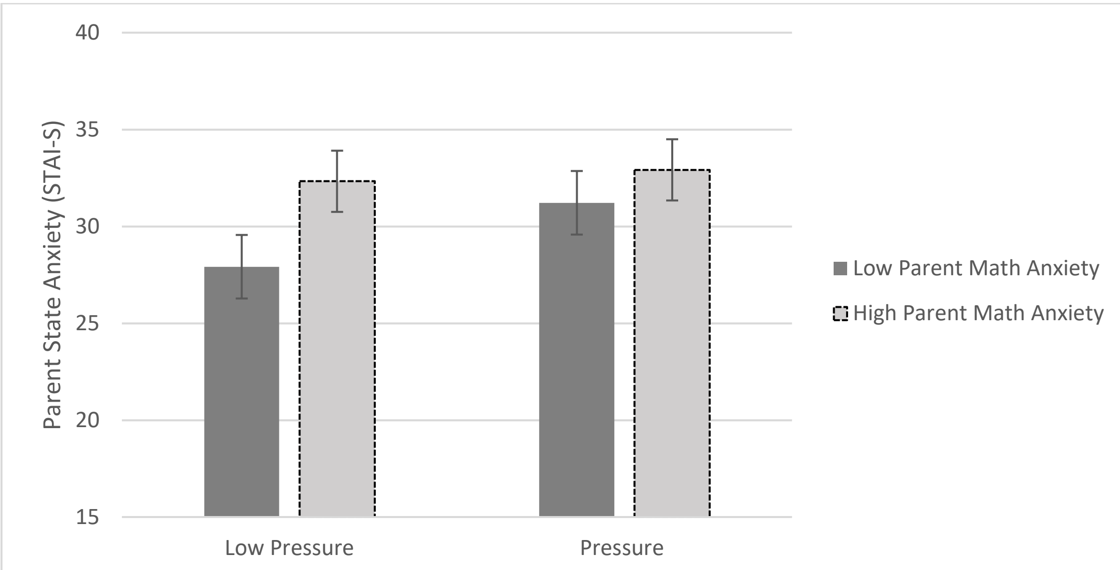
I next sought to determine how parent math anxiety was related to perceived anxiety/pressure following the parent/child math interaction. Within the entire sample, a positive, marginally significant correlation was found between parent math anxiety and reported state anxiety as measured by the STAI-S (r= 0.19, p=0.061). Overall, based on a median split, parents high in math anxiety reported greater state anxiety as measured by the STAI-S following the math interaction than parents who were low in math anxiety: t(96)= -2.06, p=0.042 (high math anxiety: M= 32.63, SD= 8.25, low math anxiety: M= 29.47, SD= 7.75). Additionally, parents who were high math anxious reported greater performance pressure in supporting their child and helping them to perform well on the math problems: t(95)= -2.55, p=0.012 (high math anxiety: M= 4.48, SD= 1.64, low math anxiety: M= 3.57, SD= 1.86). There were no differences between high and low math anxious parents in how well they thought their child performed in the math interaction (p=0.67).

When further broken down into the pressure and low pressure conditions, there were no differences in reported parent state anxiety in the pressure condition between those parents who were high and low in math anxiety (based on a median split): t(46) = -0.80, p=0.43 (high math anxiety: M=32.92, SD= 7.89, low math anxiety: M= 31.22, SD= 7.89). There was a trend for high math anxious parents within the pressure condition to report higher performance pressure than low math anxious parents: t(45)= -1.51, p=0.14 (high math anxiety: M= 4.75, SD= 1.85, low math anxiety: M= 3.91, SD= 1.95). There were no differences in the pressure condition between parents who were high and low math anxious in their ratings of how well they thought their child performed during the math interaction: $t(42.84)= 0.00$, $p=1.00$ (high math anxiety: M= 5.09, SD= 1.89, low pressure: M= 5.09, SD= 1.59).

Within the low pressure condition, parents who were high math anxious reported higher state anxiety as measured by the STAI-S than parents low in math anxiety (based on a median split): $t(48)= -2.00$, $p=0.053$ (high math anxiety: M= 32.33, SD= 8.78, low math anxiety: M= 27.92, SD= 7.43), though the relationship was marginally significant. For the performance pressure specific question, high math anxious parents reported higher performance pressure than low math anxious parents in the low pressure condition: $t(48)= -2.09$, $p=0.042$ (high math anxiety: M= 4.21, SD= 1.38, low math anxiety: M= 3.27, SD= 1.76). There were no differences between high and low math anxious parents in the low pressure condition in how well parents felt their children performed on the math problems: $t(35.09)= 1.51$, $p=0.14$ (high math anxiety: M= 5.77, SD= 1.07, low math anxiety: M= 5.96, SD= 1.04).

Across the pressure and low pressure conditions, low math anxious individuals in the low pressure condition reported the lowest state anxiety levels as measured by the STAI-S. High math anxious parents in the low pressure condition reported higher levels of STAI-S than low math anxious parents in this condition, and high math anxious parent's ratings of state anxiety in the low pressure condition were similar to those ratings of state anxiety of both high and low math anxious parents in the pressure condition. This indicates that performing math in a low pressure condition for high math anxious parents induces a similar level of state anxiety as a high pressure condition for low math anxious parents (Figure 5, means and standard deviations presented in the above text). Overall, these results regarding math anxiety and perceived pressure suggest that reported ratings of anxiety/pressure across the pressure/low pressure conditions were modified by a parent's math anxiety levels.

Figure 5. (Exp. 2) Subjective parent's state anxiety ratings following the parent/child math interaction as measured by the STAI-S. The means depicted here are based on a median split of math anxiety.



Parent/Child Math Interaction Performance

Across the entire sample, children and parents on average attempted half of the problems provided (M= 6.15, SD= 3.3, range: 2-15 problems). On average, children and parents got nearly all of the questions correct that they attempted (Total correct: M= 5.83, SD= 3.06; percentage correct: M= 95.91% correct, SD= 0.88%). To determine whether performance differed based on the pressure condition, independent samples t-tests were run that compared the average number of problems attempted across the conditions, the average number of correct problems across the conditions, and the percent correct across the conditions. On average, children in the low pressure condition got fewer problems correct: $t(96)= -2.48$, $p= 0.015$, (pressure: M=6.58, SD=3.25, low pressure: M=5.10, SD=2.64), attempted fewer problems: $t(96)= -2.92$, $p= 0.004$, (pressure: M=7.10, SD=3.48, low pressure: M=5.24, SD=2.83), but got a greater percentage of problems correct overall: $t(65.13)= 2.70$, $p= 0.008$, (pressure: $M=93.51$, $SD=10.91$, low pressure: $M=98.22$, $SD=4.97$). Individuals within the pressure condition attempted more problems, likely due to the fact that they were told children finished all of the provided problems within ten minutes. However, the percentage of those answers that they provided that were correct were lower than those individuals in the low pressure condition. The answers were provided for those individuals within the low pressure condition, which explains why those individuals within the low pressure condition got nearly 100% of the questions correct. Despite the fact that the problems to be solved were at a first grade level (as tested in a pilot study) and the children had help from their parents, there were still significant differences in the overall percentage correct due to the pressure condition. These differences in accuracy further support the claim that the pressure manipulation was indeed successful.

Due to the low number of subjects within the pressure condition ($n=48$) and the high accuracy (and low variability) that existed within the pressure condition, it is difficult to determine statistically how both parent trait/state anxiety and children's trait/state anxiety interact to influence children's math performance. However, it is possible to generally explore how each of these factors may have individually contributed to decrements in math performance in the pressure condition. I examined the factors that were associated with baseline math performance, which included parent and child math anxiety, children's WM, children's baseline math performance, parent's highest level of education completed, and the family's annual gross income. I also examined the relation between children's math performance and parent and child state anxiety. Within the pressure condition, children's math anxiety, though non-significant, was negatively related to math performance ($r= -0.21$, $p=0.16$). Children's state anxiety showed a significant, negative relation with math performance during the parent/child interaction ($r= -0.32$, p=0.026). Parent math anxiety and parent state anxiety as reported by the STAI-S were not related to child math performance in the pressure condition (p=0.4 and p=0.48, respectively), though the correlation with math performance was negative. Parent's report of pressure was not related to math performance (p=0.92). Additionally, children's WM and children's baseline math performance were not related to math performance in the pressure condition (p=0.16 and p=0.62), though the relation between WM and math performance under pressure was positive. Parent's highest level of education completed was positively correlated with children's math performance under pressure (r= 0.37, p=0.011).

Woodcock Johnson Performance

The Woodcock Johnson achievement test was administered to the child following the parent/child interaction. A child's W-score represents how well she or he did on the applied problems of the Woodcock Johnson achievement test. Within the entire sample, W-scores were normally distributed (M= 470.13, SD= 23.35, range: 417-526). An independent samples t-test showed no differences in W-scores between the pressure and low pressure conditions: t(96)= -0.28, p=0.78. The absence of a difference in math performance between the pressure and low pressure conditions may be attributed to the fact that W-scores measure a child's overall academic math achievement that is greatly influenced by the child's educational experiences and prior math knowledge. It is possible that if the math measure used following the parent/child interaction were more closely related to the type of problems completed with the parent, a difference in child's math performance following the math interaction would be seen across the two conditions. Despite the lack of differences between the pressure and low pressure conditions, it is still possible to examine the effects of trait math anxiety and state anxiety of both the child and the parent on the child's W-scores because the pressure condition was shown to be successful at inducing higher perceived anxiety/pressure in the children and parents, and it was shown to have behavioral effects on the children's math performance during the interaction.

Prior to exploring how trait math anxiety, state anxiety, and children's WM related to children's W-scores measured after the parent/child interaction, the relation of W-scores to variables previously demonstrated to impact baseline math performance were examined in order to determine potential covariates. Within the entire sample, baseline math performance was positively associated with the children's W-scores ($r= 0.61$, $p<0.001$), parent's highest level of education was positively related to W-scores ($r= 0.40$, $p<0.001$), the family's annual gross income was positively related to W-scores ($r= 0.27$, $p=0.008$), and children's age was positively related to W-scores ($r= 0.38$, $p<0.001$). The number of math classes taken by the parent was not related to the children's W-scores. To determine how each of these variables predicted W-scores while controlling for the other variables, a linear regression was run in which these four factors served as independent variables, and the children's W-scores served as the dependent variable. The overall model was significant: $F(4,95)= 21.34$, $p<0.001$, with an adjusted R square value of 0.46. When controlling for the other factors, the parent's highest level of education was significantly related to children's math performance: $B= 0.33$, $p=0.002$, children's age was significantly related to math performance: $B= 0.24$, $p=0.003$, and baseline math task performance was significantly related to children's W-scores: $B= 0.48$, $p<0.001$. Annual gross income was no longer significant ($p=0.23$). As such, in the analyses that explore the effects of anxiety (trait and state) and WM on children's math performance, parent's highest level of education, children's age, and children's baseline math performance were included as covariates.

To speak to the question of how trait math anxiety may interact with state anxiety to affect children's math performance, I examined child and parent math anxiety separately due to the low number of subjects collected thus far and due to the absence of a relation in our sample between child math anxiety and parent math anxiety. A univariate ANOVA was run in which pressure/low pressure, a median split of children's WM, a median split of children's math anxiety, and a median split of children's state anxiety were treated as independent variables. Math performance as measured by W-scores on the Woodcock Johnson achievement test served as the dependent variable. In addition to controlling for parent's highest level of education, children's age and children's baseline math performance, parent's math anxiety and parent's state anxiety levels as measured by the STAI-S were also included as covariates. There was a significant main effect of children's math anxiety: $F(1,77)= 12.00$, $p=0.001$, such that those children who were highly math anxious demonstrated lower math performance than those children identified as low math anxious. The main effect of children's WM approached significance: $F(1,77)= 3.02$, $p=0.086$, with those children with higher WM capacity demonstrating higher W-scores than those with lower WM capacity. The two-way interaction of WM and children's state anxiety approached significance: $F(1,77)=3.40$, $p=0.069$. Children with high WM did not differ in math performance based on state anxiety. Children with low WM who reported high state anxiety performed similarly to those children with high WM. Children with low WM who reported low state anxiety demonstrated the lowest math performance. The two-way interaction of children's math anxiety and children's state anxiety also approached significance: $F(1,77)=3.42$, $p=0.068$. Children who were highly math anxious had similar math performance across high and low state anxiety. Children who were low math anxious and demonstrated low state anxiety performed similarly to children who were high math anxious. Children who were low math anxious and showed high state anxiety showed the highest math performance. Lastly, the three-way interaction of children's WM, children's math anxiety, and children's state anxiety was significant: $F(1,77)= 4.70$, $p=0.033$. Children of low WM with both low and high math anxiety showed increases in performance with increased state anxiety, though the children with high math anxiety showed lower performance generally than those children with low math anxiety. Children of high WM with low math anxiety showed increases in performance with increased state anxiety, and children of high WM with high math anxiety showed large declines in performance with increased state anxiety (Figure 6 and Table 4). These results demonstrate a compound effect of children's trait and state anxiety on children's math performance that is moderated by children's WM capacity. Generally low WM children benefit from state anxiety regardless of children's math anxiety, though high math anxious children show lower math performance than low math anxious children when experiencing both low and high state anxiety. High WM children benefit from high state anxiety when their math anxiety levels are low. When math anxiety is high and state anxiety is high for high WM children, math performance plummets.

Figure 6. (Exp. 2) Children's math performance following the parent/child interaction, as measured by W scores computed from the Woodcock Johnson math achievement test

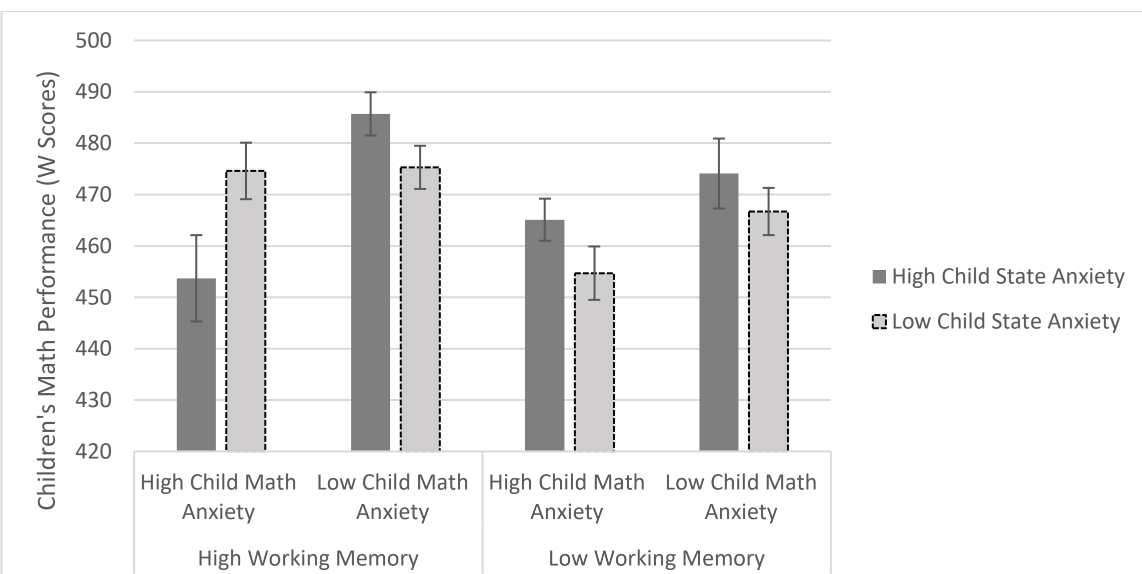


Table 4: (Exp. 2) Descriptive statistics for children's math performance, as measured by W scores, on the Woodcock Johnson math achievement measure for children high and low in WM, high and low in math anxiety, and high and low in state anxiety (each based on a median split)

WM Capacity	Math Anxiety	State Anxiety	Mean	S.E.
High	High	High	453.7	8.4
		Low	474.6	5.5
	Low	High	485.7	4.2
		Low	475.3	4.2
Low	High	High	465.1	4.1
		Low	454.7	5.2
	Low	High	474.1	6.8
		Low	466.7	4.6

To determine how parent math anxiety and parent state anxiety may interact with children's WM to impact children's math performance on the Woodcock Johnson achievement test, a similar univariate ANOVA was run. The independent variables tested were pressure/low pressure, a median split of children's WM, a median split of parent's math anxiety, and a median split of parent's state anxiety as measured by the STAI-S. The STAI-S was chosen as the anxiety measure as it is in line with our first experiment and as it showed a positive trend with children's math performance ($r= 0.131$, $p=0.20$), whereas parent's perceived pressure was unrelated to children's math performance ($p=0.57$). Math performance as measured by children's W-scores served as the dependent variable. In addition to controlling for children's age, children's baseline math performance, and parent's highest level of education, children's math anxiety and state anxiety levels were also included as covariates. The main effect of children's WM was significant: $F(1, 77)= 7.05$, $p=0.010$, with higher WM children performing better than lower WM children. The three-way interaction of children's WM, parent math anxiety, and parent state anxiety approached significance: $F(1, 77)$: 2.24, $p=0.14$. In low WM children whose parents had low math anxiety, state anxiety did not affect children's math performance. Low WM children whose parents had high math anxiety and low state anxiety showed math performance similar to those children with low WM whose parents had low math anxiety. Low WM children whose parents had high math anxiety and high state anxiety showed higher math performance than all other low WM children. For high WM children whose parents had low math anxiety, children's math performance was higher for parents who reported higher state anxiety. Children with high WM whose parents had high math anxiety and low state anxiety performed similarly to children whose parents had low math anxiety and high state anxiety. Children with high WM whose parents reported high math anxiety and high state anxiety showed small declines in performance as compared to those children with high WM whose parents had high math anxiety and reported low state anxiety (Figure 7 and Table 5).

Figure 7. (Exp. 2) Children's math performance following the parent/child interaction, as measured by W scores computed from the Woodcock Johnson math achievement test

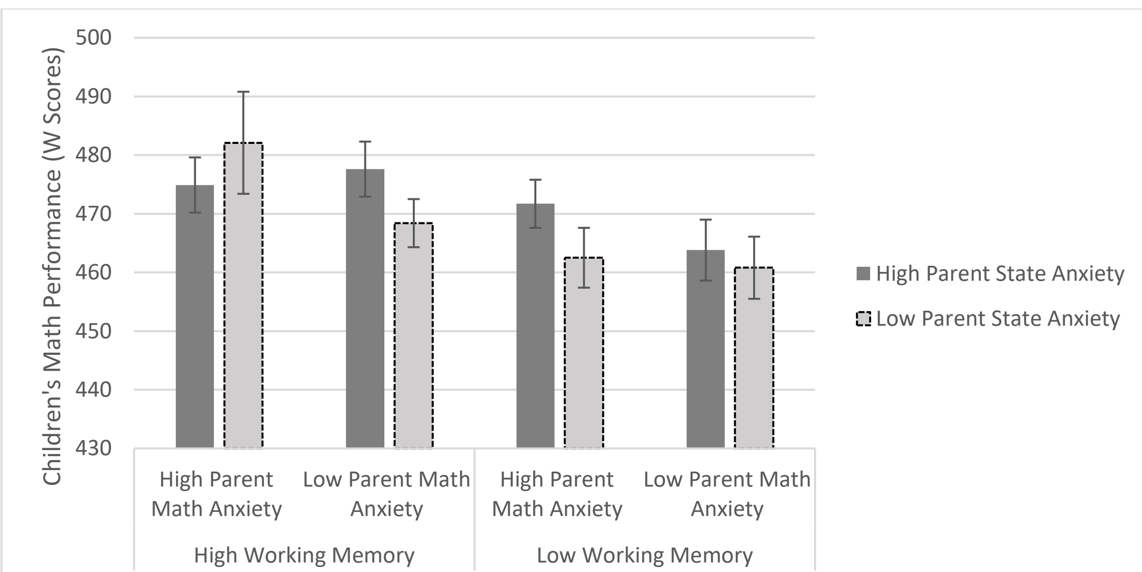


Table 5: (Exp. 2) Descriptive statistics for children's math performance, as measured by W scores, on the Woodcock Johnson math achievement measure for children high and low in WM, parents high and low in math anxiety, and parents high and low in state anxiety (each based on a median split)

WM Capacity	Math Anxiety	State Anxiety	Mean	S.E.
High	High	High	474.9	4.7
		Low	482.1	8.7
	Low	High	477.6	4.7
		Low	468.4	4.1
Low	High	High	471.7	4.1
		Low	462.5	5.1
	Low	High	463.8	5.2
		Low	460.8	5.3

These results are trending and more power is necessary to detect a significant effect. It is possible that with greater power and less variability a compound effect of parent's math anxiety and state anxiety on children's math performance would be observed. The overall trend of results is in line with the effects of children's math and state anxiety on children's performance. The effects of children's own math and state anxieties on performance were greater, which makes sense as parents are indirectly related to children's performance in this scenario. It is of course possible that parent's math anxiety, children's math anxiety, parent's state anxiety, children's state anxiety, and children's WM capacity all interact to affect children's math performance. However, our study is currently underpowered to properly address this question.

Parent Modular Arithmetic (MA) Performance: Pressure, Cognitive Demand, and Math/State Anxiety

Following the parent/child interaction, parents completed the modular arithmetic (MA) task. To determine how parent math performance was affected after the parent/child math interaction, a univariate ANOVA was run in which pressure/low pressure served as the independent variable and total MA accuracy (across low and high demand problems) served as the dependent variable. Parent's highest level of education was entered as a covariate as it was significantly related to MA accuracy performance. Pressure had an overall effect on total MA accuracy: $F(1, 93)= 4.10$, $p=0.046$, with parents in the pressure condition showing lower MA accuracy than parents in the low pressure condition. To determine whether high cognitive demand problems and low cognitive demand problems were differentially affected by pressure (i.e. whether pressure affected parent's WM capacity), separate univariate ANOVAs were run for each, with pressure/low pressure serving as the independent variable and high cognitive demand accuracy and low cognitive demand accuracy serving as the dependent variables, respectively. In each of these models, parent's highest level of education completed was entered as a covariate. There was a marginally significant effect of pressure on high cognitive demand problems: $F(1, 93)=6.48$, $p=0.065$, whereby parents in the pressure condition had lower accuracy on high cognitive demand problems than parents in the low pressure condition. There was no effect of pressure on the accuracy of low demand problems. Overall, parents had higher accuracy on low demand problems (see Table 6 for means and standard deviations of MA accuracy, percent correct, on high and low demand problems). These results demonstrate that parents show declines in accuracy performance on cognitively demanding problems after pressure as compared to low pressure conditions, while performance on low demand problems is not affected by the pressure manipulation. These results are in line with previous findings (Beilock & Carr, 2005).

Table 6: (Exp. 2) Descriptive statistics for parent modular arithmetic (MA) accuracy (% correct) in the low pressure/pressure condition for problems of high and low cognitive demand

Condition	WM Demand	Mean	S.E.
Low Pressure	Low	97.0	1.6
	High	82.2	2.2
High Pressure	Low	94.1	1.6
	High	76.2	2.3

To determine whether a speed/accuracy tradeoff was responsible for the decreased accuracy observed after pressure, univariate ANOVAs were run in which pressure/low pressure was the independent variable and reaction time on high cognitive demand problems and low cognitive demand problems served as the dependent variables, respectively. The family's annual gross income served as a covariate in each of these models as it was positively associated with reaction time performance. There was a significant effect of pressure on high demand reaction time: $F(1,93)=14.75$, $p<0.001$. However, it does not signify a speed/accuracy trade-off. On high demand problems, parents in the pressure condition demonstrated significantly slower reaction times as compared to the low pressure condition (rather than significantly faster RT, which would signify a speed/accuracy trade-off). In other words, parents are showing declines in performance in both accuracy and reaction time after pressure as compared to the low pressure condition. There was a significant effect of pressure on low demand reaction time as well: $F(1, 93)=3.96$, $p=0.050$. Parents in the pressure condition were slower than parents in the low pressure condition. Additionally, parents were faster overall on low demand problems than on high demand problems (see Table 7 for means and standard deviations of MA reaction times, milliseconds, on high and low demand problems). This demonstrates that parents took longer to complete problems under the pressure condition as compared to the low pressure condition, and the slower reaction time on high demand problems did not result in improved accuracy on high demand problems after pressure.

Table 7: (Exp. 2) Descriptive statistics for parent modular arithmetic (MA) reaction times (ms) in the low pressure/pressure condition for problems of high and low cognitive demand

Condition	WM Demand	Mean	S.E.
Low Pressure	Low	2959.34	219.37
	High	8626.94	760.06
High Pressure	Low	3596.38	228.90
	High	12887.59	793.07

Reductions in high demand accuracy after pressure and increased reaction time each signify a reduction in performance after pressure, and therefore a composite performance metric was computed that combined z-scores for accuracy and inverted z-scores for reaction times. This metric was used to again examine performance after pressure/low pressure. A univariate ANOVA was run in which the composite score for high demand performance served as the dependent variable and pressure/low pressure served as the independent variable. Both the parent's education level and the family's annual gross income served as covariates. There was a significant effect of pressure: $F(1, 92)=15.98$, $p<0.001$, such that individuals underperformed after pressure as compared to low pressure. A similar univariate analysis was run for low demand problems, and there was a marginally significant effect of pressure: $F(1,92)=2.96$, $p=0.089$, whereby parents underperformed after pressure as compared to those parents after low pressure (see Table 8 for all means and standard deviations of MA composite performance, accuracy and reaction times, on high and low demand problems). These results suggest that not only is there a decline in parent's WM resources after pressure, but there is also a decline in math performance on problems that rely on more simple recall procedures.

Table 8: (Exp. 2) Descriptive statistics for parent modular arithmetic (MA) performance (z-scores composite measure) in the low pressure/pressure condition for problems of high and low cognitive demand

Condition	WM Demand	Mean	S.E.
Low Pressure	Low	0.31	0.23
	High	0.50	0.17
High Pressure	Low	-0.28	0.24
	High	-0.5	0.18

To determine how math anxiety impacted performance on high demand MA problems a univariate ANOVA was run in pressure/low pressure and a median split of parent's math anxiety served as the independent variables, and the composite performance measure of high demand problems served as the dependent variable. The highest level of parent education completed and the family's annual gross income were statistically controlled for as covariates. There was a significant main effect of math anxiety: $F(1,90)=8.24$, $p=0.005$, whereby parents who were higher in math anxiety demonstrated worse performance on high demand problems overall than individuals who were lower in math anxiety. The two-way interaction of pressure and math anxiety was not significant: $F(1,90)=1.78$, $p=0.19$. Both high and low math anxious individuals show declines in performance in the pressure condition as compared to the low pressure condition. Low math anxious individuals in the low pressure condition show the highest performance on high cognitive demand problems. High math anxious individuals in the low pressure condition show a decline in performance in comparison to low math anxious individuals in the same condition, though the decline is not significant. Low math anxious individuals in the pressure condition show MA performance similar to those high math anxious parents in the low pressure condition. High math anxious parents after pressure show the greatest declines in high cognitive demand MA performance (Figure 8 and Table 9). These results demonstrate a compound effect of pressure and math anxiety to influence performance on problems that are high in cognitive demand and tax WM resources.

Figure 8. (Exp. 2) Modular arithmetic (MA) performance (composite z-score of accuracy and reaction times) for high and low cognitively demanding problems under the low pressure and pressure conditions as a function of parent math anxiety.

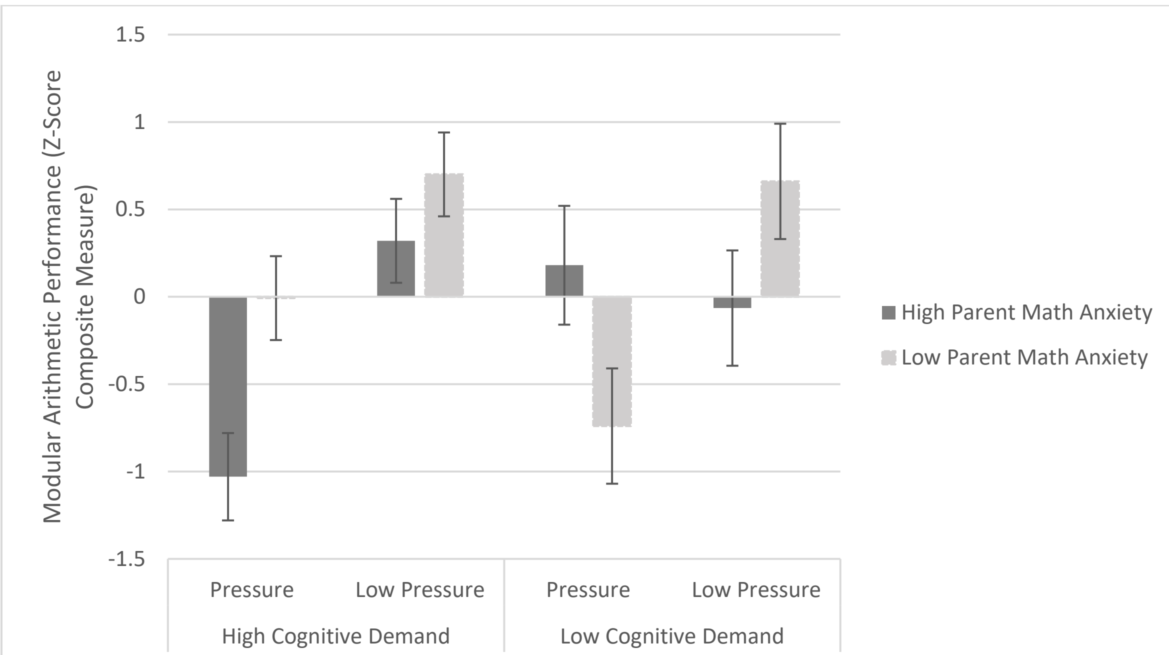


Table 9: (Exp. 2) Descriptive statistics for parent modular arithmetic (MA) performance (z-scores composite measure) in the low pressure/pressure condition for problems of high and low cognitive demand as moderated by parent's math anxiety

WM Demand	Condition	Parent Math Anxiety	Mean	S.E.
High	Low Pressure	High	0.32	0.24
		Low	0.7	0.24
	Pressure	High	-1.03	0.25
		Low	-0.008	0.24
Low	Low Pressure	High	-0.065	0.33
		Low	0.66	0.33
	Pressure	High	0.18	0.34
		Low	-0.74	0.33

The effects of pressure and math anxiety on low cognitive demand performance were examined in a univariate ANOVA in which the composite measure for low demand performance served as the dependent variable, while pressure/low pressure and a median split of parent math anxiety were the independent variables. Education levels of the parents and the family's annual gross income were entered as covariates. There was no main effect of parent math anxiety on parent's low demand performance. There was a significant interaction of pressure and parent's math anxiety on low demand performance: $F(1, 90)=6.23$, $p=0.014$. Parents in the low pressure condition who were low math anxious showed the greatest performance on low demand problems. Performance was lower for high math anxious parents in the low pressure condition than for low math anxious parents. Low math anxious parents in the pressure condition showed the lowest performance on low demand problems, while high math anxious parents in the pressure condition showed performance similar to high math anxious parents in the low pressure condition (Figure 8 and Table 9). One possible explanation for why individuals within the pressure condition who are low math anxious show declines in low demand performance may be that cognitive resources are being drawn away from the low demand problems to perform well on the high demand problems.

The interactive effects of pressure/low pressure, parent math anxiety, and parent's reported levels of pressure on high demand MA performance was examined with a univariate ANOVA in which each of these factors served as the independent variables and the composite measure for high demand performance served as the dependent measure. Parent education and family annual gross income were entered as covariates. Perceived pressure was utilized in place of parent ratings of STAI-S as these ratings correlated with MA performance. The two-way interactions were not significant and the three-way interaction was not significant. However, looking at the trends graphically illuminates an interesting relation between these three variables (Figure 9 and Table 10). Those parents who are low math anxious and in the low pressure condition demonstrate the highest overall performance on high cognitively demanding problems, and performance does not differ based on reported levels of pressure. Parents who are high math anxious and in the low pressure condition show performance similar to low math anxious parents if they report low levels of perceived pressure. Parents who are high math anxious and report higher levels of pressure in the low pressure condition show lower levels of math performance, though not significantly so. Within the pressure condition, low math anxious parents who report high pressure show the greater math performance. Low math anxious parents who report low pressure show declines in math performance. High math anxious parents in the pressure condition show the lowest math performance of all groups, and their performance does not vary as a function of reported perceived pressure. These results are not significant, though they are in line with what would be hypothesized. Ultimately, low math anxiety results in higher math performance after experiencing low pressure. High math anxiety results in low math performance in a low pressure condition if those high math anxious parents report high levels of perceived pressure. In the pressure condition, high math anxious adults show the largest decrements in performance regardless of perceived pressure. It is likely that the compound effect of experiencing pressure and having high trait anxiety results in large performance declines regardless of pressure perceptions. Those parents who are low math anxious and experience pressure show improvements in performance if they report high perceptions of pressure, as the experienced anxiety likely has not become debilitating but rather aids in performance possibly through increased attention to the task at hand or through increased motivation.

Figure 9. (Exp. 2) Modular arithmetic (MA) performance (composite z-score of accuracy and reaction times) for high cognitively demanding problems under the low pressure and pressure conditions as a function of parent math anxiety and parent reported pressure (i.e. state anxiety)

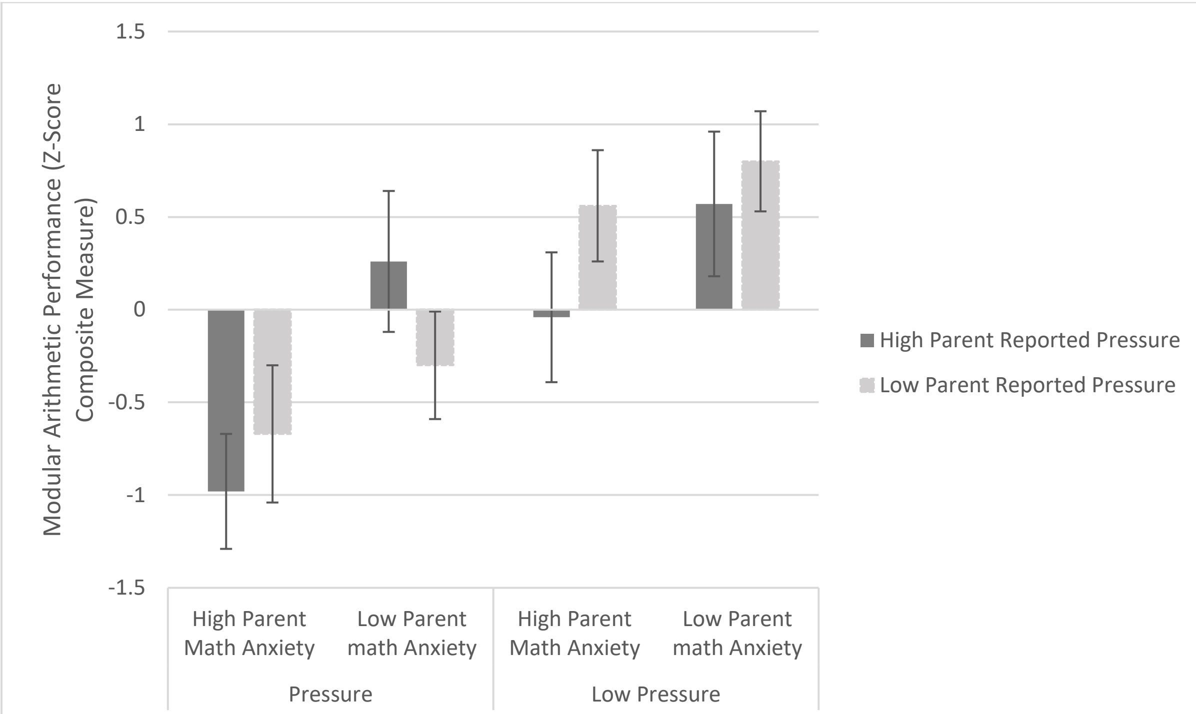


Table 10: (Exp. 2) Descriptive statistics for parent modular arithmetic (MA) performance (z-scores composite measure) in the low pressure/pressure condition for problems of high cognitive demand as moderated by parent's math anxiety and reported ratings of pressure

Condition	Parent Math Anxiety	Pressure Ratings	Mean	S.E.
Low Pressure	Low	High	0.57	0.39
		Low	0.8	0.27
	High	High	-0.041	0.35
		Low	0.56	0.3
Pressure	Low	High	0.26	0.38
		Low	-0.3	0.29
	High	High	-0.98	0.31
		Low	-0.67	0.37

The effects of pressure/low pressure, parent math anxiety, and parent perceived pressure on low demand composite performance was examined with a univariate ANOVA in which low demand performance served as the dependent variable, and parent education and family annual gross income were entered as covariates. The main effect of pressure approached significance: $F(1, 85)= 2.95$, $p=0.089$, with performance after pressure being lower than performance after low pressure. The main effect of reported perceived pressure also approached significance: $F(1, 85)= 3.52$, $p=0.064$, with parents who reported greater pressure showing lower math performance than those parents who reported feeling less pressure. The two-way interaction of pressure condition and parent math anxiety was significant: $F(1, 85)= 24.15$, $p=0.002$. Parents who were low in math anxiety and in the low pressure condition showed higher performance on low demand problems than those parents who were high in math anxiety in the low pressure condition. Parents who were low in math anxiety and in the pressure condition demonstrated lower performance who were high in math anxiety and in the pressure condition. Additionally, the three-way interaction of pressure condition, parent math anxiety, and parent's reports of perceived pressure approached significance: $F(1, 85)= 8.65$, $p=0.054$.

Figure 10. (Exp. 2) Modular arithmetic (MA) performance (composite z-score of accuracy and reaction times) for low cognitively demanding problems under the low pressure and pressure conditions as a function of parent math anxiety and parent reported pressure (i.e. state anxiety)

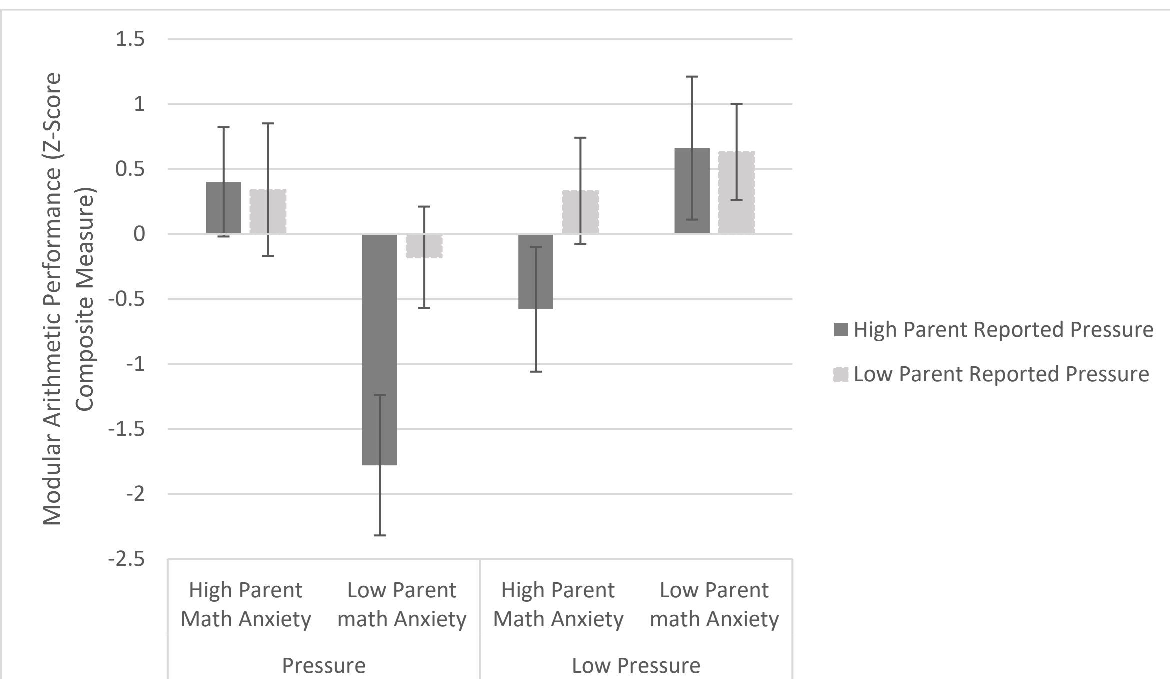


Table 11: (Exp. 2) Descriptive statistics for parent modular arithmetic (MA) performance (z-scores composite measure) in the low pressure/pressure condition for problems of low cognitive demand as moderated by parent's math anxiety and reported ratings of pressure

Condition	Parent Math Anxiety	Pressure Ratings	Mean	S.E.
Low Pressure	Low	High	0.66	0.55
		Low	0.63	0.37
	High	High	-0.58	0.48
		Low	0.33	0.41
Pressure	Low	High	-1.78	0.54
		Low	-0.18	0.39
	High	High	0.4	0.42
		Low	0.34	0.51

When examining the relation graphically (Figure 10 and Table 11), once again parents with low math anxiety within the low pressure condition perform the best on low demand problems, and this performance does not vary based on reports of perceived pressure. Parents of high math anxiety in the low pressure condition show declines in performance if they report high levels of perceived pressure. If they report low levels of perceived pressure they perform similarly on low demand problems to those parents who are low in math anxiety in the low pressure condition. These results in the low pressure condition are in line with predictions whereby high trait anxiety and high reports of pressure show a compound effect to negatively impact performance on low demand problems when the pressure to perform was low. Within the pressure condition, the results are more difficult to interpret. Those parents who are highly math anxious and in the pressure condition perform well on low demand problems, similar to the performance of low math anxious parents in the low pressure condition, and their performance does not vary as a function of reported perceived pressure. Low math anxious parents in the pressure condition demonstrate lower performance on low demand problems than that of high math anxious parents, and the performance of low math anxious parents is moderated by parent's perceived levels of pressure. Low math anxious parents who report low pressure in the pressure condition show performance that is similar to high math anxious parents in the pressure condition, and low math anxious parents who report high pressure in the pressure condition show large declines in performance on low demand problems. One possible explanation of this may be that those parents who use WM resources to perform well on high demand problems after pressure (i.e. those parents who are low in math anxiety and high in perceived pressure) ultimately exhaust resources that may be used on problems that rely on procedural recall. The high performance of high math anxious parents after pressure may be a result of increased anxiety/arousal drawing attention/motivation toward problems that are easier for these parents to solve.

Discussion

This study was the first study to my knowledge that tested parents and children in a situation designed to elicit increases in state anxiety/perceived pressure, and the manipulation was successful at eliciting increased perceptions of anxiety/pressure. Both parents and children who completed a parent/child math interaction under pressure reported greater perceived anxiety/pressure following the interaction than parents and children who completed a parent/child math interaction under low pressure. Low math anxious parents showed higher ratings of anxiety/pressure if they were in the pressure condition as compared to the low math anxious parents in the low pressure condition. High math anxious parents showed no differences in ratings of anxiety/pressure between the two conditions, suggesting that high math anxious parents experience high state anxiety regardless of pressure. Children who were in the low pressure condition showed no differences in reported state anxiety based on high or low math anxiety. Children in the pressure condition with low math anxiety reported greater state anxiety than those children in the low pressure condition. Children in the pressure condition with high math anxiety reported the highest state anxiety. These results suggest that not only did the pressure manipulation work, but that ratings of anxiety were moderated by children's math anxiety. In parents, highly math anxious individuals reported higher state anxiety even in the low pressure condition. This was not the case in children. Those children in the low pressure condition experienced similar levels of state anxiety regardless of math anxiety. Ultimately, the low pressure condition was successful at creating a low pressure environment for children and for parents of low math anxiety.

In addition to showing differences in anxiety perceptions across the conditions, children showed differences across the conditions in math performance on the actual math interaction task. This was somewhat surprising as parents were allowed to help their children solve problems and the problems were at a first grade level, but it further demonstrates that the pressure condition was successful at inducing higher pressure and lower performance for those individuals in that condition. However, the low variability in performance in this condition, the low number of subjects, and the fact that parents aided in children's performance all stood as reasons to look to a difference performance measure to determine how trait math anxieties and state anxieties interacted to affect children's math performance. Children completed a math achievement measure following the interaction, which was used as our performance measure.

To address how trait math anxiety and state anxiety interacted to affect children's math performance on a math achievement measure, I examined children's and parent's trait and state anxieties separately. This was warranted as parent math anxiety and children's math anxiety were not correlated and also due to the low number of subjects currently collected. Overall there were no differences in children's math achievement measured after the parent/child interaction between the pressure and low pressure groups, likely due to the fact that children's prior educational experiences and math knowledge affect achievement measures. Despite a lack of difference in children's math performance across the conditions, state anxieties differed in children across the conditions which allowed for the examination of how math trait anxiety and state anxiety impacted children's math performance. As WM has been demonstrated to moderate the effects of anxiety/pressure on performance (Beilock & Carr, 2005; Ramirez et al., 2013), children's WM capacity was also considered as a factor in children's math performance. I found that children of low WM performed lower overall than children of high WM. Children of low WM who were low math anxious performed better than children of low WM who were high math anxious. Children of low WM who reported high levels of state anxiety showed increases in performance, whether they were low or high math anxious. It is possible that for these children increased state anxiety increases attention or motivation, which aids in math performance. A different pattern emerged for children who were high in WM. Children who were of high WM and low math anxiety showed increases in performance if they reported high levels of state anxiety. Overall, those children showed the highest math performance. High WM children who were high in math anxiety but reported low levels of state anxiety performed similarly to those children who were low in math anxiety and low in state anxiety. Children who were high in WM and high in math anxiety showed drastic declines in math performance if they also reported high state anxiety. That is to say, there was a compound effect of trait math anxiety and state anxiety in children with high WM, likely due to the debilitative effects of extreme anxiety on available WM resources. Previous research has demonstrated that children's math performance is strongly linked to WM (McLean & Hitch, 1999; Holmes & Adams, 2006; Rasmussen & Bisanz, 2005; Gathercole & Pickering, 2000). One particular study demonstrated that children as low as third and fourth grade show declines in math performance in a pressure situation that is dependent on

WM (Wang & Shah, 2014), such that high WM children show declines in math performance under pressure, which is in line with the adult literature on choking under pressure (Beilock et al., 2004; Beilock & Carr, 2005; Beilock & DeCaro, 2007). Additionally, a link has been observed between children's math anxiety, children's WM, and children's math achievement (Ramirez et al., 2013), whereby those children with high WM and high math anxiety show declines in math performance. Our results demonstrate that math anxiety in children is particularly debilitative when a child experiences high state anxiety related to math performance, though only for children high in WM. It is likely that for these children worries induced from high trait and state anxiety consume WM resources that may otherwise be used for the task at hand to perform well.

I also examined separately the effects of parent's math anxiety and parent's reported levels of state anxiety on children's math performance, as moderated by children's WM. Though not significant, a similar trend was found as discussed above for children. Children who were low in WM whose parents were low in math anxiety showed the lowest math performance, and their performance did not differ based on parent's reports of state anxiety. Low WM children whose parents reported high math anxiety and high state anxiety showed increased performance compared to high math anxious parents who reported low state anxiety. In this case, increased state anxiety for high math anxious parents led to increases in performance for children. It is possible that this increased state anxiety led to greater motivation within the parent, which ultimately impacts the child, though the mechanism through which this occurs is unclear. For children high in WM, low parent state anxiety and low parent math anxiety is associated with decreased performance as compared children whose parents report low math anxiety and high parent state anxiety. Children high in WM whose parents are high math anxiety perform the best when parents report lower levels of state anxiety. Ultimately, across the groups, increased state anxiety in the parent is associated with increased performance as compared to parents of low state anxiety, with the exception of parents who report high math anxiety and have children with high WM. These children show slight, nonsignificant declines in math performance if their parent's report high levels of math anxiety and state anxiety. These effects are not significant and are only trending. It is possible with more data collection they will become significant. It is also possible that the effects will remain small as this is a one shot interaction, and the previously observed effects of parent's math anxieties on children's achievement are reported across the school year after numerous interactions together at home (Maloney et al., 2015). It is also not entirely surprising that the effects are small as I am examining the effects of another individual's anxieties on someone's performance. The mechanisms through which parent's anxieties affect children's performance remain unclear, though one possible explanation may be that parents are motivating their children differently or affecting their children's attention differently based on their anxieties. Future work will look to the videotaped interactions to address possible mechanisms.

Parent's performance on the MA problems following the math interaction also shows a compound negative effect of trait math anxiety and state anxiety. Overall, parents in the pressure condition showed decreases in math performance following the pressure condition as compared to the low pressure condition. These effects were observed for both low cognitively demanding problems and high cognitively demanding problems. This effect was modified in a step-wise fashion for high cognitively demanding problems by parent's reported math anxiety. Within the low pressure condition, parents low in math anxiety show the highest performance on cognitively demanding problems. Parents high in math anxiety in the low pressure condition show declines in performance as compared to those parents low in math anxiety. After pressure, parents low in math anxiety decline in math performance on high cognitively demand problems as compared to the low pressure condition. Their performance is similar to parents who report high math anxiety in the low pressure condition. This suggests that math anxiety in parents in the low pressure condition is similar to the behavioral effects of pressure on performance for parents who are low in math anxiety. Those parents who have high math anxiety and experience pressure show the largest declines in performance, reflecting a compound effect of math anxiety and state anxiety on math performance. The compound effects of both trait anxiety and state anxiety created through a pressure situation causes debilitative effects on math performance. These effects are further qualified by the subjective pressure parents report, though not significantly so. If parents in the low pressure condition who are high math anxious report low pressure, their performance does not decline as compared to low math anxious parents. If parents in the pressure condition who are low math anxious report low pressure, their performance declines. For low math anxious parents in the pressure condition, this lack of reported pressure may signify a lack of arousal that may affect attention/motivation to rise to the occasion and perform well when the stakes are high. Ultimately, this step-wise decline in math performance on high demand problems suggests that parent's WM resources may be compromised following the parent/child math interaction, and it is possible that these compromises in WM resources affects how they interact with their child over math. Future work will look to relate these declines in math performance on high demand problems to the videotaped interactions.

Parent's math performance on low demand problems also shows effects of pressure, math anxiety, and state anxiety. Those parents in the low pressure condition who are low in math anxiety show higher performance than those parents in the low pressure condition who were high in math anxiety. That is to say, math anxiety has a negative impact on math performance even on low demand problems in a low pressure condition. This is modified in an anticipated direction by parents reported pressure. If high math anxious parents report low pressure in a low pressure condition, they perform better than high math anxious parents who reported higher pressure. The relation between state anxiety and trait anxiety within the pressure condition is harder to interpret. Those parents who are high in trait math anxiety show performance similar to parents low in math anxiety in the low pressure condition. Additionally, those parents who were low math anxious showed the largest declines in performance if they also reported high state anxiety. I might expect results on low demand problems that are in line with the effects of trait math anxiety and state anxiety reported on high demand problems. Alternatively, I might expect to see no differences on low demand performance due to the ease of the problems, which is in line with previous findings (Beilock & Carr, 2005; Beilock & DeCaro, 2007). However, previous research on MA performance was conducted with college age adults who are familiar with testing situations and may have more recent experience completing math problems in a testing-similar situation. One possible explanation for these results may be that parents who are high math anxious divert their cognitive resources to low demand problems under pressure as they are easier to complete due to their reliance on procedural recall. Additionally, they may be particularly motivated to perform well on these problems as they may feel unable to complete the more difficult, cognitively demanding problems. Low math anxious parents may show declines on low demand problems particularly if they report high state anxiety as their cognitive resources are exhausted on high cognitive demand problems where they perform the best. This interpretation is speculative, but could provide a possible explanation for the unexpected findings. Additionally, it is possible that individual differences in parent’s WM capacity or differences in parent's baseline math performance may shed light on these unexpected results and the results described above for performance on high demand problems. Future studies that explore parent's math performance after a math interaction with their children ought to measure parent's baseline math performance and WM capacity to better under how parents respond to this type of pressure.

GENERAL DISCUSSION

The current studies explored the effects of trait math anxiety and situationally induced state anxiety on math performance, and the cognitive mechanisms associated with declines in math performance. Prior research has studied the effects of each of these types of anxieties individually on math performance, though no studies have examined their interaction. I studied these effects in two unique populations that are both negatively impacted by math anxiety: undergraduate adults after experiencing pressure in the lab and parents/children following a homework-like situation in the lab.

In experiment 1, I replicate previous studies in demonstrating that adults show declines in math performance on high cognitively demanding problems when completing math problems under pressure (Beilock & Carr, 2005), though this study extended previous findings by demonstrating that low math anxious individuals are likely driving these decrements as they start off with higher math performance in a low pressure scenario. Upon experiencing pressure, performance declines. High math anxious individuals show poor initial performance on cognitively demanding problems under low pressure, and performance does not further decline under pressure. It is likely that for high math anxious individuals the 'low pressure' situation is not perceived as low pressure, which is why their initial performance suffers as compared to low math anxious individuals. Unfortunately, the design of our experiment did not allow for this to be directly tested.

In experiment 2, I show that high WM children who report heightened state anxiety following a math pressure interaction with their parent show declines in math performance if they also have high math anxiety. Ultimately, I show a compound, negative effect of children's math anxiety and state anxiety on children's math performance. Children who are highly math anxious and report low levels of state anxiety exhibit performance that is similar to low math anxious children. This suggests that the negative effects of math anxiety can be attenuated if a child does not perceive the situation to be anxiety-inducing. For low WM children, increased state anxiety leads to increased math performance, regardless of math anxiety, possibly through increased attention or motivation to perform well. In experiment 2, I also show a compound effect of math anxiety and state anxiety on parent's math performance. Parents with low math anxiety in the low pressure condition performed the best on cognitively demanding problems. High math anxiety in the low pressure condition caused declines in parent's math performance as compared to low math anxious parents in the same condition. Low math anxious parents performed worse after pressure than low math anxious parents after low pressure and performed similarly to high math anxious parents in the low pressure condition. Ultimately, high math anxiety was having behavioral effects on math performance in a low pressure condition that were similar in effect to the effects of pressure on low math anxious parents. Parents who were high math anxious and completed the pressure condition performed the worst. These results were further moderated by parent's reported levels of perceived pressure (i.e. state anxiety), though not statistically so. Interestingly, if high math anxious parents in the low pressure condition report low state anxiety, their math performance is similar to that of low math anxious parents.

These results suggest that declines in math performance for math anxious individuals (both children and parents) may be attenuated through reductions in perceived state anxiety levels.

Theoretical Implications

The current results suggest that relation between math anxiety and math performance is not ubiquitously negative. Our results from experiment 2 suggest that reductions in levels of state anxiety that a highly math anxious individual experiences can reduce the negative effects of trait math anxiety on math performance. The assumption associated with the attenuation in math performance declines in the current study is that those individuals who report less state anxiety are experiencing fewer worries and ruminations that are co-opting WM resources otherwise used to solve the math problems. This is in line, though indirectly, with prior research. Expressive writing has been associated with increases in an individual's WM capacity (Klein & Boals, 2001), and expressive writing interventions have been shown to alleviate the negative effects of anxiety on performance both in the lab and in classrooms (Ramirez & Beilock, 2011; Park et al., 2014). When students wrote about anxiety-related thoughts and worries prior to completing an exam or an in-lab measure, the negative effects of both test anxiety and math anxiety were attenuated. The results are interpreted as negative thoughts and ruminations being off-loaded through expressive writing, ultimately freeing WM resources for the task at hand.

Importantly, the study that explored the benefits of expressive writing on math anxiety examined this relation in adults who attended undergraduate university. In the current study, improvements in math performance for those high math anxious individuals who experience low state anxiety suggest that both children and parents may benefit from interventions that alter how individual's respond to/interpret anxiety. Interventions to limit the deleterious effects of math anxiety in children are limited, though consecutive, positive math experiences in the lab (i.e. high success on math problems adjusted for their ability) lead math anxious children to report declines in their math anxiety levels (Jansen et al., 2013). It is not always possible in school situations to tailor children's math experiences for their ability, though it may be possible to equip children with the tools necessary to respond proactively to their anxiety. Possible tools may include expressive writing interventions, whereby math anxious children learn at a young age to express their anxieties on paper before performing math (Park et al., 2014) or learn reappraisal techniques that help children interpret arousal as a sign that they will perform well (Jamieson et al., 2010). The current results suggest that children as young as first grade may benefit from interventions aimed specifically for this age group, and it may be most beneficial to begin with these techniques at a young age as math anxiety increases with age (Dowker et al., 2016). Offsetting the cycle between increased math anxiety and decreased math performance through child interventions at a young age may help combat the negative effects of math anxiety that strengthen over time (Hembree, 1990).

Additionally, the negative effects of math anxious parents on children's math achievement across the school year have been documented (Maloney et al., 2015). It remains unclear what it is about homework helping behavior in math anxious parents that results in low math performance in children. Ultimately, providing parents with clear cut training programs that instruct them in how to support their children over homework would be an ideal intervention, as has been demonstrated in other academic domains (Bailey, 2006; Callahan et al., 1998), to offset the negative effects of parent's math anxiety on children's math performance. However, more recent results suggest that interacting over math in a low pressure scenario benefits children's math performance (Berkowitz et al., 2015), and the current results suggest that if an interaction is perceived to be low pressure, those reductions in parent state anxiety are associated with small, non-significant increases in children's math performance. Additionally, low levels of parent state anxiety for high math anxious parents are associated with increases in their own math performance following the parent/interaction if the interaction was low pressure. This may signify increases in the availability of parent's WM resources that may impact how they interact with their children over math. Expressive writing (Ramirez & Beilock, 2011; Park et al., 2014) and reappraisal techniques (Jamieson et al., 2010) may be designed for parents to help improve both their own experiences with math and possibly their children's experiences with math. Again, these interventions may be particularly helpful when children are young, as parents provide more homework help to elementary aged children than to children in middle school and high school (Cooper et al., 2000). Additionally, these interventions for parents would be easy and cost-effective to implement, and as such the potential benefits could be far-reaching.

Limitations & Future Studies

There were various limitations of the current studies. In experiment 1, the interaction of math anxiety, WM capacity of the participants, and situational pressure was not significant, likely due to the low number of subjects included in the study. Future studies ought to recruit more subjects to determine if the current trend reported here is in fact significant. Additionally, the experimental design did not allow for the exploration of how math anxious undergraduates perceived the 'low pressure' situation. I hypothesize that those individuals within the low pressure scenario who were highly math anxious showed initial declines in performance due to experiencing higher pressure; the situation is designated by experimenters to be low pressure, though it is possible these high math anxious individuals did not experience it as low pressure. To better understand how math anxious undergraduate adults in the lab experience this low pressure scenario and to understand how individual differences in perceived state anxiety relate to math performance, anxiety/pressure measures should be collected between the low pressure and pressure conditions to determine how math anxious individuals perceive the low pressure scenario, possibly with additional filler surveys to mask the intentions of the experimenters. Additionally, the low pressure scenario could be altered in future experiments to make it seem less stressful, possibly by including positive feedback for the participants.

Experiment 2 is underpowered and more participants are currently being run in the study. Despite the lack of power, some interesting significant effects and non-significant trends were found that could be further clarified through the inclusion of additional measures. The math performance of both children and parents benefited from some level of anxiety, and the mechanism by which anxiety improves performance in this scenario is unclear. It is possible that improved performance is due to increased motivation or increased attention to the task at hand that has not yet become debilitative (Yerkes & Dodson, 1908; Broadhurst, 1959; Deshpande & Kawane, 1982; Teigen, 1994; Eysenck et al., 2007). Future studies ought to explore how children's and parent's reported motivation or goal-directed attention relates to reported levels of anxiety. Additionally, the relation between math anxiety and math performance (of both children and of parents) calls to question whether it is anxiety itself that is associated with lower math performance or if it is a matter of lower math ability. In the analyses regarding children's math performance, children's baseline math performance was included as a covariate and parent's highest level of education was included as a covariate, therefore this is not an issue with these results. In the analyses regarding parent math performance, parent's highest level of education was again included as a covariate as was family annual gross income. Parent education level is a proxy for math knowledge that is utilized in other studies (Maloney et al., 2015), though future studies should include a variable collected within the lab that stands as a baseline measure of parent's math knowledge/ability. Additionally, WM measures were not collected for the parents in experiment 2, and ought to be collected in future studies to determine how parent WM capacity relates to math performance breakdown for high math anxious individuals.

Conclusions

Ultimately, our results show that math anxiety and state anxiety can have negative compounds effects on math performance in children and parents. However, when high math anxious children report low levels of state anxiety following a situation that induces pressure, the debilitative effects of math anxiety on math performance are reduced. Additionally, when high math anxious parents report low perceived pressure in a low pressure situation, their math performance is similar to that of low math anxious parents in a low pressure condition. To our knowledge, this is the first time this has been demonstrated. These results are important as math anxiety is prevalent across the globe and is associated with the avoidance of math and math related careers (Hembree, 1990; Ashcraft & Moore, 2009). If it is possible to introduce interventions that help reduce the amount of state anxiety that math anxious children and parents experience when doing math, it may be possible to improve math performance of children at an early age. This improved performance create more positive feelings surrounding math for children and may reduce their avoidance of math overall (Jansen et al., 2013; Hembree, 1990).

References

Alexander, L. & Martray, C. (1989). The development of an abbreviated version of the Mathematics Anxiety Rating Scale. *Measurement & Evaluation in Counseling & Development*, 22, 143-150.

Ashcraft, M. H. (2002). Math anxiety: Personal, educational, and cognitive consequences. Current Directions in Psychological Science, 11, 181-185.

Ashcraft, M.H. & Kirk, E.P. (2001). The relationships among working memory, math anxiety, and performance. Journal of Experimental Psychology: General, 130, 224-237.

Ashcraft, M.H. & Krause, J.A. (2007). Working memory, math performance, and math anxiety. Psychonomic Bulletin & Review, 14, 243-248.

Ashcraft, M.H. & Moore, A.M. (2009). Mathematics anxiety and the affective drop in performance. Journal of Psychoeducational Assessment, 27, 197-205.

Bailey, L. B. (2006). Interactive homework: A tool for fostering parent–child interactions and improving learning outcomes for at-risk young children. *Early Childhood Education Journal*, *34*, 155-167.

Beilock, S.L. & Carr, T.H. (2005). When high-powered people fail: Working memory and "choking under pressure" in math. Psychological Science, 16, 101-105.

Beilock, S.L. & DeCaro, M.S. (2007). From poor performance to success under stress: Working memory, strategy selection, and mathematical problem solving under pressure. Journal of Experimental Psychology: Learning, Memory, and Cognition, 33, 983-998.

Beilock, S.L., Kulp, C.A., Holt, L.E. & Carr, T.H. (2004). More on the fragility of performance: Choking under pressure in mathematical problem solving. Journal of Experimental Psychology: General, 133, 584-600.

Berkowitz, T., Schaeffer, M.W., Maloney, E.A., Peterson, L., Gregor, C., Levine, S.C. & Beilock, S.L. (2015). Math at home adds up to achievement in school. Science, 350, 196-198.

Broadhurst, P.L. (1959). The interaction of task difficulty and motivation: The Yerkes-Dodson law revised. Acta Psychologica, 16, 321-338.

Burns, M. (1998). Math: Facing an American phobia. Sausalito, CA: Math Solutions Publications.

Callahan, K., Rademacher, J. A., & Hildreth, B. L. (1998). The effect of parent participation in strategies to improve the homework performance of students who are at risk. *Remedial and Special Education*, *19*, 131-141.

Chang, H. & Beilock, S.L. (2016). The math anxiety-math performance link and its relation to individual and environmental factors: A review of current behavioral and psychophysiological research. Current Opinion in Behavioral Sciences, 10, 33-38.

Cooper, H., Lindsay, J.J. & Nye, B. (2000). Homework in the home: How student, family and parenting-style differences relate to the homework process. Contemporary Educational Psychology, 25, 464-487.

Coy, B., O'Brien, W.H., Tabaczynski, T., Northern, J. & Carels, R. (2011). Associations between evaluation anxiety, cognitive interference and performance on working memory tasks. Applied Cognitive Psychology, 25, 823-832.

Daneman, M., & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of verbal learning and verbal behavior*, *19*(4), 450-466.

DeCaro, M. S., Rotar, K. E., Kendra, M. S., & Beilock, S. L. (2010). Diagnosing and alleviating the impact of performance pressure on mathematical problem solving. *The Quarterly Journal of Experimental Psychology*, *63*(8), 1619-1630.

Deshpande, S.W. & Kawane, S.D. (1982). Anxiety and serial verbal learning: A test of the Yerkes-Dodson law. Asian Journal of Psychology and Education, 9, 18-23.

DeStefano, D. & LeFevre, J.A. (2004). The role of working memory in mental arithmetic. European Journal of Cognitive Psychology, 16, 353-386.

Dowker, A., Sarkar, A. & Looi, C. Y. (2016). Mathematics anxiety: What have we learned in 60 years? Frontiers in Psychology, 7.

Egloff, B., & Hock, M. (2001). Interactive effects of state anxiety and trait anxiety on emotional Stroop interference. *Personality and Individual Differences*, *31*(6), 875-882.

Engle, R. W. (2002). Working memory capacity as executive attention. *Current directions in psychological science*, *11*(1), 19-23.

Eysenck, M. & Calvo, M.G. (1992). Anxiety and performance: The processing efficiency theory. Cognition and Emotion, 6, 409-434.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7*(2), 336.

Faust, M.W., Ashcraft, M.H. & Fleck, D.E. (1996). Mathematics anxiety effects in simple and complex addition. Mathematical Cognition, 2, 25-62.

Gathercole, S. E., & Pickering, S. J. (2000). Working memory deficits in children with low achievements in the national curriculum at 7 years of age. *British Journal of Educational Psychology*, *70*(2), 177-194.

Gimmig, D. (2006). Choking under pressure and working memory capacity: When performance pressure reduces fluid intelligence. Psychonomic Bulletin & Review, 13, 1005-1010.

Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. Journal for Research in Mathematics Education, 21, 33-46.

Hitch, G.J. (1978). The role of short-term working memory in mental arithmetic. Cognitive Psychology, 10, 302-323.

Holmes, J., & Adams, J. W. (2006). Working memory and children's mathematical skills: Implications for mathematical development and mathematics curricula. *Educational Psychology*, *26*, 339-366.

Hopko, D.R., Ashcraft, M.H. & Gute, J. (1998). Mathematics anxiety and working memory: Support for the existence of a deficient inhibition mechanism. Journal of Anxiety Disorders, 12, 343-355.

Imbo, I. & Vandierendonck, A. (2007). Do multiplication and division strategies rely on executive and phonological working memory resources? Memory & Cognition, 35, 1759-1771.

Imbo, I., Vandierendonck, A. & Vergauwe, E. (2007). The role of working memory in carrying and borrowing. Psychological Research, 71, 467-483.

Jameson, M. M. (2014). Contextual factors related to math anxiety in second-grade children. The Journal of Experimental Education, 82, 518-536.

Jamieson, J. P., Mendes, W.B., Blackstock, E. & Schmader, T. (2010). Turning the knots in your stomach into bows: Reappraising arousal improves performance eon the GRE. Journal of Experimental Social Psychology, 46, 208-212.

Jansen, B. R. J., Louwerse, J., Straatemeier, M., Van der Ven, S. H.G., Klinkenberg, S. & Van der Maas, H.L.J. (2013). The influence of experiencing success in math on math anxiety, perceived math competence, and math performance. Learning and Individual Differences, 24, 190-197.

Klein, K. & Boals, A. (2001). Expressive writing can increase working memory capacity. Journal of Experimental Psychology: General, 130, 520-533.

Maloney, E.A. & Beilock, S.L. (2012). Math anxiety: Who has it, why it develops, and how to guard against it. Trends in Cognitive Sciences, 16, 404-406.

Maloney, E.A., Ramirez, G., Gunderson, E.A., Levine, S.C. & Beilock, S.L. (2015). Intergenerational effects of parents' math anxiety on children's math achievement and anxiety. Psychological Science, 26, 1480-1488.

McLean, J. F., & Hitch, G. J. (1999). Working memory impairments in children with specific arithmetic learning difficulties. *Journal of experimental child psychology*, *74*, 240-260.

Miyake, A. & Shah, P. (1999). Models of working memory: Mechanisms of active maintenance and executive control. New York: University Press.

OECD: PISA 2012 Results: Ready to Learn: Students' Engagement Drive and Self-Beliefs (Volume III). PISA, OECD Publishing; 2013.

Owens, M., Stevenson, J., Norgate, R. & Hadwin, J.A. (2008). Processing efficiency theory in children: Working memory as a mediator between trait anxiety and academic performance. Anxiety, Stress, and Coping: An international Journal, 21, 417-430.

Patall, E.A., Cooper, H., Robinson, J.C. (2008). Parent involvement in homework: A research synthesis. Review of Educational Research, 78, 1039-1101.

Park, D., Ramirez, G., & Beilock, S. L. (2014). The role of expressive writing in math anxiety. *Journal of Experimental Psychology: Applied*, *20*(2), 103.

Pressman, R.M., Sugarman, D.B., Nemon, M.L., Desjarlais, J., Owens, J.A. & Schettini-Evans, A. (2015). Homework and family stress: With consideration of parents' self confidence, educational level, and cultural background. The American Journal of Family Therapy, 43, 297-313.

Ramirez, G. & Beilock, S.L. (2011). Writing about testing worries boosts exam performance in the classroom. Science, 331, 211-213.

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

Rasmussen, C., & Bisanz, J. (2005). Representation and working memory in early arithmetic. *Journal of experimental child psychology*, *91*, 137-157.

Sattizahn, J. R., Moser, J. S., & Beilock, S. L. (2016). A Closer Look at Who "Chokes Under Pressure". *Journal of Applied Research in Memory and Cognition*, *5*(4), 470-477.

Seyler, D.J., Kirk, E.P. & Ashcraft, M.H. (2003). Elementary subtraction. Journal of Experimental Psychology: Learning, Memory, and Cognition, 29, 1339-1352.

Solomon, Y., Warin, J. & Lewis, C. (2002). Helping with homework? Homework as a site of tension for parents and teenagers. British Educational Research Journal, 28, 603-622.

Spielberger, C. D., & Gorsuch, R. L. (1983). *State-Trait Anxiety Inventory for Adults: Manual and Sample: Manual, Instrument and Scoring Guide*. Consulting Psychologists Press.

Teigen, K. H. (1994). Yerkes-Dodson: A law for all seasons. Theory and Psychology, 4, 525-547.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent?. *Journal of memory and language*, *28*(2), 127-154.

Unsworth, N., Heitz, R. P., Schrock, J. C., & Engle, R. W. (2005). An automated version of the operation span task. *Behavior research methods,37*(3), 498-505.

Vukovic, R. K., Kieffer, M. J., Bailey, S. P., & Harari, R. R. (2013). Mathematics anxiety in young children: Concurrent and longitudinal associations with mathematical performance. *Contemporary educational psychology*, *38*(1), 1-10.

Wang, Z. & Shah, P. (2014). The effect of pressure on high and low-working-memory students: An elaboration of the choking under pressure hypothesis. British Journal of Educational Psychology, 84, 226-238.

Wigfield, A. & Meece, J.L. (1988). Math anxiety in elementary and secondary school students. Journal of Educational Psychology, 80, 210-216.

Wiley, J. & Jarosz, A.F. (2012). Working memory capacity, attentional focus, and problem solving. Current Directions in Psychological Science, 21, 258-262.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). Woodcock–Johnson III tests of achievement. Itasca, IL: Riverside.

Wu, S. S., Barth, M., Amin, H., Malcarne, V. & Menon, V. (2012). Math anxiety in second and third graders and its relation to mathematics achievement. Frontiers in Psychology, 3.

Yerkes, R.M. & Dodson, J.D. (1908). The relation of strength of stimulus to rapidity of habit-formation. Journal of Comparative Neurology and Psychology, 18, 459-482.

Zaslavsky, C. (1994). Fear of math, how to get over it and get on with your life. New Brunswick, NJ: Rutgers University Press.

Appendix A: Baseline Math Task for Children

<u>Step 1.</u>
Say, "Now we are going to solve 6 problems. I want you to solve each problem as quickly as possible without making too many mistakes. I want you to say your answer aloud as soon you have it. For example, can you tell me what do you think is the answer for 2+1? (wait for answer). Ok, let's get started.

<u>Step 2.</u>

- Scoring: Score each correct response 1 and each incorrect response 0.
- Child's response: Write down the actual response provided.

	ANS	Child's response	Score (1,0)
Example	7	9	0
1	10		
2	15		
3	19		
4	23		
5	6		
6	26		

1. A school bus picked up 3 children in the first stop and then 7 in the second stop. How many children did the school bus pick up?
2. If you had 6 pennies and someone gave you 9 more, how many pennies would you have altogether?
3. Leslie received 5 candles yesterday and she was given 14 more candles today. How many candles does Leslie have altogether?
4. If one child has 8 cups and another child has 15 cups. How many cups would they have altogether?
5. Jeff has 2 blocks. His sister gives Jeff 4 more blocks. How many blocks does Jeff have altogether?
6. Stacy has 9 cars. Her brother gives her 17 more cars. How many cars does Stacy have altogether?

Appendix B: Instructions Given in Math Interaction Video

High Pressure Instructions Given in Video:

In our lab we are very interested in understanding how children learn math. Children learn math in a lot of different ways. Part of math learning occurs in school, but research shows children also learn math at home. In particular, an important time for learning occurs when children are interacting with their parents when they do homework. In fact, a student's achievement in math class often reflects the type of support that their parents provide when they are doing homework. For example, high quality support and input from parents often results in more math learning and higher grades for students. The goal of this study is to better understand how parents interact with their children when doing homework.

In order to answer this question, we would like for you to work on a few math problems with your child that are similar to what you would see on a homework assignment from school. We will give you a set of problems, and we would like you to help your child work through the problems and solve them as if your child were doing these problems for a homework assignment that they needed to get a good grade on. If your child gets stuck on a problem, work through the problem together to get the answer. Similar to a homework assignment, we will be grading the problems afterwards. At the end of the session, the experimenter will give your child feedback about how well they did on the math problems compared to other children who have participated in the study. The experimenter will also give you individualized feedback on ways you could better support your child's math learning based on how well your child does. Remember, research has shown that parents play a key role in their children's success on these types of tasks, so your support will be very important.

Before you begin, please follow the instructions on the computer screen to answer a few questions.

Low Pressure Instructions Given in Video:

In our lab we are very interested in understanding how children learn math. Children learn math in a lot of different ways. Part of math learning occurs in school, but research shows children also learn math at home. The goal of this study is to better understand how parents interact with their kids when doing math.

In order to answer this question, we would like for you to work on a few math problems with your child. We will give you a set of problems, and we would like you to help your child work through the problems and solve them. If your child gets stuck on a problem, don't worry, just work through the problem together to get the answer. We will not be checking your child's answers when you're finished, as we're really only interested in your general interaction. The answers will be available to you as you solve the problems.

Before you begin, please follow the instructions on the computer screen to answer a few questions.

Appendix C: Math Problems in the Math Interaction Task

Popsicle Fun! A Popsicle is just tasty flavored ice stuck to a wooden stick. It's really easy to make, too – so easy, that the first Popsicles were created by accident! 11-year-old Frances Epperson was mixing a flavoring for water and soda on his porch, and left the mixture outside overnight with a stirring stick still in it. When the temperatures dropped over night, the drink froze to the stick, leaving the delicious treat. These days ice pops can be made in all sorts of flavors and shapes – just pour your favorite juice or soda into a fun ice tray or Popsicle mold, place a stick as a handle into the mixture, and leave it in your freezer for a few hours. We like to make Popsicles in the morning so that when we come home from a fun day of outdoor activities, we have a cold, summer treat waiting to be enjoyed!

1) A camp counselor brings in Popsicles for all of the campers. She has 17 cherry- flavored Popsicles and 15 lemon-flavored Popsicles. How many Popsicles are there in all?
2) If Maria's mom made 25 Popsicles, and Maria and her brother ate 12 of them during a heat-wave last week, how many Popsicles are left?
3) You buy a fireworks Popsicle and a ring Popsicle.
    a) How much do you pay for both Popsicles?
    b) If you pay with 6 quarters, how much change will you get?
4) Anne makes 6 of her favorite orange-juice Popsicles. To pass the time while the juice is freezing, she decides to have some counting fun
    a) First, Anne decides to count down from 110 by 5s. What numbers should Anne say?
    110 _____ ______ _____ _____ _____
    b) Anne decides to switch to a new counting rule. What is the counting rule Anne uses if these are the numbers she says: 14, 21, 28, 35 …..
5) This clock shows what time the Popsicles came out of the freezer. How many minutes are left until it will be a quarter-past 2pm?
6) A variety-pack of Popsicles has 3 cherry, 3 orange, and 4 grape flavored Popsicles. What fraction of the total Popsicles are cherry-flavored?
7) David's Popsicle mold can make 4 Popsicles at the same time. How many times does David need to fill and freeze the Popsicle mold to make 16 Popsicles?
8) If you put juice in the freezer to make Popsicles at 12:15pm and they are ready to eat just 4 hours later, what time can you eat your delicious Popsicles?
9) If Peter, John and Rachel have 15 Popsicles to share amongst themselves, how many Popsicles can they each have?
10) This chart shows how many kids at the playground like each flavor Popsicle.
    a) Put the Popsicle flavors in order of popularity (from most to least popular) and list how many kids like each flavor.
    b) Which flavor do kids like more: orange or lime?
    c) Which flavor is the most popular? Which flavor is the least popular?
    d) If one box of Popsicles has 4 lemon, 3 cherry and 2 orange, how many boxes of Popsicles do you need to get to have enough of each of those flavors for the kids who want them?