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ADULT MATH ANXIETY:

RELATION TO MATH PERFORMANCE AND ADULT/CHILD MATH INTERACTIONS

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ABSTRACT

In a series of studies, I investigate the individual and inter-generational effects of math anxiety and performance pressure. Adults who suffer from math anxiety tend to underperform in math, and the children in their care tend to have lower math achievement levels. In study 1, I test out a novel intervention designed to improve math performance by freeing up working memory resources compromised by anxiety. I found that, on math problems that place high demands on working memory, young adults' math anxiety was negatively related to math performance. Further, a drawing intervention condition, which involved having participants express their emotions through art before the math task, resulted in higher performance on challenging math problems than a control condition. In Study 2, I investigate the intergenerational impacts of math anxiety and performance pressure, exploring how parent math anxiety and the level of pressure one is put under during a math interaction impacts parent/child math interactions. I found that adults who were math anxious or in a high-pressure condition provided lower quality math instruction to their children as measured by a modified teacher rating scale. Parents under pressure were also more intrusive, taking over more of the work of generating problem solving strategies from their child as compared to those in the lower pressure condition. In Study 3, I tested an intervention designed to break the link between high parent math anxiety and poor student math performance in a lower income sample. I found that a math app that had previously been found to be successful in breaking this link in a higher income sample was not effective in this sample, potentially due to much lower app usage. These findings contribute to our understanding of the relation between math anxiety and math achievement, both within and between individuals, identify a novel way to intervene at the individual level, and set the stage for future studies that aim to intervene to cut the tie between math anxiety and math achievement.

INTRODUCTION

General Overview

Students' and parents' emotions and attitudes about mathematics are associated with student math performance beginning as early as first grade, and extending throughout schooling and beyond (Berkowitz et al., 2015; Park, Gunderson, Tsukayama, Levine & Beilock, 2016; Gunderson, Donnellan, Robins & Trzesniewski, 2018). Students who have been put in a high-pressure, anxiety-inducing situation underperform on working-memory intensive tasks (Walker & Spence, 1964; Beilock & Carr, 2005; Ramirez & Beilock, 2011). Similarly, students who suffer from math anxiety, defined as feeling fearful or apprehensive about math, show performance deficits on math tasks, and particularly on more difficult math tasks (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Dowker, Sarkar & Looi, 2016).

Unfortunately, math anxiety is common both in the United States and throughout the world, and students who struggle in math are at a disadvantage when it comes to pursuing Science Technology Engineering and Math careers (Foley et al., 2017). This link between anxiety and performance does not only operate at the individual level. Rather, when a child has a parent or teacher who is math anxious, that child tends to underperform in math, and this relation holds even controlling for other potential explanatory factors (Beilock, Gunderson, Ramirez & Levine, 2009; Berkowitz, et al., 2015). This finding suggests that there are not only negative effects of math anxiety within an individual, but inter-generational effects of math anxiety that are negatively related to children's math achievement.

I aim to first identify, and then mitigate, the impact of math anxiety on individual performance and on instruction. I first review the link between math anxiety and performance at the individual level in my introduction, Chapter 1. Then, in Chapter 2, I report on Study 1, in which I tested a novel intervention designed to break the link between math anxiety and math performance by providing participants with potential ways to offload the negative emotions taking a toll on their working memory capacity. In Chapter 3/Study 2, I use two novel coding schemes to test whether the math interactions of math-anxious parents and their children are characterized by certain features. I do this by exploring whether parents who are under pressure and/or who are highly math anxious offer subpar math teaching to their children, providing a potential mechanism for the intergenerational relation of adult math anxiety and child math achievement. Finally, in Chapter 4/Study 3, I test out an intervention that was shown to mitigate the impact of parent math anxiety on child math achievement in a higher income sample, is effective in breaking the link between parent math anxiety and child math achievement in a lower income sample. In order to lay the framework for addressing these issues, in this introduction I review the literature with regard to the following questions:

1.) What does the evidence from studies of pressure and math anxiety reveal about how anxiety relates to math performance at the individual level?

2.) What types of interventions have thus far been effective in breaking the relation between anxiety and performance at the individual level?

3.) What does the evidence from studies of pressure and math anxiety reveal about how parent math anxiety relates to child math performance?

4.) What types of interventions have thus far been effective in breaking the relation between parent math anxiety and child math performance?

Background and Significance

1.) What Does the Evidence from Studies of Pressure and Math Anxiety Reveal About How Anxiety Relates to Math Performance at the Individual Level?

In this section, I discuss the effect of anxiety, caused by a high-pressure situation, on math performance. I then go on to examine how trait math anxiety relates to math performance. Finally, I discuss working memory, a system that allows one to remember and manipulate information for a short time, as a mechanism by which anxiety impacts performance (Miyake & Shah, 1999; Engle, Kane, & Tuholski, 1999; Ashcraft & Kirk, 2001; Beilock & Carr, 2005).

Pressure and Performance.

Participants who undergo a pressure induction to elicit anxiety prior to test-taking often under-perform compared to participants in a non-pressure control condition. Janet Taylor Spence (Taylor, 1958) conducted pioneering work investigating the relation between pressure and performance. In her 1958 study, participants memorized syllables. After they had attempted to recall a list of these syllables, participants in the experimental pressure condition were told that they were performing poorly, whereas those in the control condition were not given negative feedback. When the participants went on to memorize a new list of syllables, those in the pressure condition underperformed as compared to the control group.

Since 1958, many subsequent studies have provided further evidence that individuals underperform when under pressure, especially individuals who have high working memory capacity, or when the task places high demand on working memory (Walker & Spence, 1964; Ashcraft & Kirk, 2001; Walton & Cohen, 2011; Ramirez & Beilock, 2011). For example, Beilock and Carr (2005) found similar results in the following pressure-inducing situation. They told participants that each participant was being randomly assigned to a partner. Further, they were told that if both partners performed well on a math test, they would each receive $5, and that their partner had already performed well. Thus, participants were led to believe that another person was counting on them to do well. Participants were also videotaped and told that teachers would be watching their performance. Beilock and Carr found that individuals with high working memory capacity showed performance deficits on difficult problems in the pressure condition whereas those with low working memory capacity did not show deficits in performance under pressure.

Wang and Shah (2014) conducted a similar study on elementary school children in China. In their study children solved three column addition problems including those where it was necessary to use carrying. A subset of the problems were called 'hidden carry' problems, where carrying was required in all of the three columns of the addition problem, but this was only apparent after solving the first two columns (example from Wang and Shah (2014): 867+639). Under neutral conditions, children with high working memory capacity outperformed those with low working memory capacity. Then, the children were put under pressure in a manipulation in which children were told that their performance on a math task would be filmed and viewed by American education experts. On addition problems that required normal carrying the high-and low- working memory children performed similarly, presumably because pressure was compromising the working memory capacity of the high working memory children. However, for problems that required hidden carrying, high working memory children outperformed the low working memory children. The investigators suggest that on normal carrying problems, the high working memory children under pressure switched to a lower working memory strategy. However, on the hidden carrying problems, because there was no low-working memory strategy they could use to solve these problems, children with high working memory capacity could not switch to an easier strategy while under pressure and thus on these problems they still outperformed their lower working memory peers.

Interestingly, the relation between pressure and performance has not always been found to be linear. Some evidence suggests that while too much pressure is associated with poor task performance, the right amount of pressure can be beneficial. Yerkes and Dodson (1908) proposed that anxiety functions as an inverted-U with too much or too little anxiety impairing performance, and the right amount optimizing performance. Yerkes and Dodson first noted this inverted-U relation in rats, who were being taught to enter a white box rather than a black box. They found that the level of electrical shock which led to the best performance followed an inverted-U function, with severe and very mild shocks less effective for learning than intermediate shocks. This relation appears to be more complicated in human beings. Wang et al., (2015) found that math anxiety and math performance followed an inverted-U relation only in students who reported being intrinsically motivated to do well in math, and only on certain math tasks. The pattern held on tasks involving combining or manipulating numbers, but not on tasks concerned with number estimation. For those showing less intrinsic motivation, the relation between anxiety and performance was linear and negative.

Math Anxiety and Performance.

Inducing anxiety through a pressure manipulation is one way to examine the effects of anxiety on performance. Another method of getting at this relationship is to measure the baseline trait anxiety of participants, and study how that anxiety is related to performance. For example, in the 1950's Janet Taylor Spence created a Manifest Anxiety Scale (MAS), to measure how much anxiety participants were feeling, and then measure how anxiety related to performance on cognitive tasks (Taylor & Spence, 1952; Herts & Beilock, 2017). The Manifest Anxiety Scale was developed from the Minnesota Multiphasic Personality Inventory (MMPI; Hathaway & McKinley, 1940). Spence found that higher scores in the MAS were associated with decreased performance on demanding cognitive tasks, like learning a complex pattern or writing backwards and upside down (Taylor & Spence, 1952).

Math anxiety is one type of trait anxiety that is associated with performance deficits. People who feel anxiety about the prospect of doing math generally do not do as well at math as those who are less math anxious (Beilock & Carr, 2005; Maloney, Risko, Ansari, & Fugelsang, 2010; Ramirez, Chang, Maloney, Levine, & Beilock, 2016). Math anxiety is of particular interest, as it is often associated with poor math performance and seems to emerge in early elementary school (Tobias, 1993; Rossnan, 2006; Ramirez et al., 2016; Berkowitz et al., 2015). Math anxiety is correlated with other types of anxiety, including test anxiety and general anxiety, but different measures of math anxiety tend to be more correlated with one another than with other types of anxiety (Ashcraft & Ridley, 2005; Dowker et al., 2016).

Math Anxiety is a common occurrence. In the United States, twenty-five percent of four-year college student and 80% of community college students report experiencing moderate or high levels of math anxiety (Hembree, 1990). Internationally, the Programme for International Student Assessment (PISA), used a series of four questions to measure the math anxiety of 15-year-old students around the world (Foley et al., 2017). They found that math anxiety was prevalent throughout the world and associated with lower math performance. In 63 of the 64 countries that took part in the 2012 PISA test, students' math anxiety score was negatively associated with their math test performance. Furthermore, nations that had high average rates of math anxiety underperformed compared to those with lower average rates of math anxiety. This relation even existed among high performing East Asian nations.

Math anxiety can be measured via surveys such as the four questions that the PISA test asked or longer standardized surveys. For example, the short, 25-item Math Anxiety Rating Scale (sMARS), asks participants how nervous or anxious they feel during math classes, as well as during everyday activities such as calculating sales tax, or a tip (Alexander & Martray, 1989) whereas the longer version, the 98-item MARS (Suinn, Edie, Nicoletti & Spinelli, 1972) goes in to more detail, for example asking participants how they feel when trying to figure out if they've been overcharged for dinner (Suinn & Winston, 2003). There are also physiological and neurological correlates of math anxiety, with, for example, math anxious individuals and displaying activation in regions of the brain associated with pain while waiting to do math (Pletzer, Kronbichler, Nuerk & Kerschbaum, 2015; Lyons & Beilock 2011).

There is also evidence that high math anxious individuals may suffer from basic performance deficits in math (Maloney et al., 2010; Maloney, Ansari & Fugelsang, 2011; Gunderson, Park, Maloney, Beilock & Levine, 2018). For example, Gunderson et al., (2018) found that math achievement in first and second grades predicted later math anxiety and vice versa, with math achievement being a better predictor of later anxiety than the reverse. Furthermore, math anxious adults tend to show deficits in quickly estimating how many squares are displayed on a screen, or which of two numerals or sets of dots is larger (Maloney et al., 2010; Maloney et al., 2011). These deficits could lead to math anxiety and avoidance, which in turn could further harm math performance and increase math anxiety, creating a self-reinforcing cycle of math anxiety and poor math performance. Indeed, math anxious individuals avoid math. They tend to take fewer math classes, go in to STEM careers at lower rates, and are even willing to give up a monetary reward to avoid math (Hembree, 1990; Chinn, 2012; Choe, Jenifer, Rozek, Berman & Beilock, 2019).

Working Memory and Anxiety.

Anxiety has long been associated with performance deficits, especially for individuals with high working memory, or on tasks that place high demands on working memory (Walker & Spence, 1964; Beilock & Carr, 2005; Foley et al., 2017). Anxiety is thought to impair performance on complex tasks by taking up working memory resources that would otherwise be used for cognitive performance (Dowker et al., 2016). When working memory is overloaded by anxiety, people become less able to use that system to manipulate numbers, patterns, letters, or other items involved in complex cognitive processing.

Evidence that anxiety impairs working memory involves the greater toll that anxiety seems to take on the cognitive performance of high working memory individuals. As discussed previously, pressure manipulations often create the biggest performance deficits for those with high working memory capacity, or on tasks that are working-memory intensive (Beilock & Carr, 2005). Furthermore, in the aforementioned study of PISA results, the relation between math anxiety and math performance was strongest for the highest performing students (Foley et al., 2017). A quantile regression revealed that students scoring in the 90^{th} percentile experienced a larger drop in math performance for every unit increase in math anxiety than those scoring in the 10^{th} percentile. This again provides evidence consistent with the role of working memory in the anxiety-poor performance link. Similarly, elementary school children with high working memory capacity also demonstrate a greater deficit in math performance based on math anxiety than their lower working memory peers, as Ramirez et al. (2016) found. The high working memory children who were not math anxious relied on efficient strategies, like carrying, to solve addition and subtraction problems. However, when their working memory was compromised by anxiety, these children switched to less working memory intensive, and less effective problem-solving strategies such as counting fingers, and thus underperformed their high working memory, non-math anxious peers. Lower working memory children, in contrast, did not show this effect, as they relied on low-working memory intensive, less efficient strategies whether or not they were anxious.

Just as high working memory individuals are most negatively impacted by anxiety, performance on high working memory tasks is most compromised by anxiety. Math anxious individuals struggle the most with tasks that require cognitive resources, like addition with borrowing, or having to remember a letter when solving a math problem (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007). These tasks show performance deficits associated with anxiety, whereas simpler tasks do not. DeCaro, Rotar, Kendra & Beilock (2010) suggest that it is the verbal ruminations associated with worrying that ties up working memory resources. They found that when under pressure, participants underperformed on verbal, but not spatial, mathematical problems. Talking out loud while solving the problems broke the link between pressure and poor performance, indicating that verbal working memory being occupied by worry may be involved in the anxiety-performance link.

2.) What Types of Interventions Have Been Effective in Breaking the Relation Between Anxiety and Performance at the Individual Level?

In this section, I discuss interventions that have been found to improve math performance by addressing anxiety. I discuss in turn interventions aimed at re-framing physiological arousal, activating or downplaying group membership, and offloading anxiety through writing.

Arousal Reappraisal Interventions.

Changing that way that one thinks about anxiety or about the task at hand has been found to be an effective means of improving performance in the face of anxiety (Walton & Cohen, 2011; Dowker et al., 2016). For example, interventions that change the interpretation of the physiological effects of anxiety have been effective at breaking the anxiety-performance link. Jamieson, Mendes, Blackstock & Schmader (2010) found that when students were told that physiological arousal suggests readiness to succeed, they performed significantly better on the math portion of the GRE than those who were not taught this re-appraisal technique. A follow-up study found that when community college students in a math class were instructed that stress is beneficial to performance, they outperformed those who were instructed to simply ignore stress (Jamieson, Peters, Greenwood & Altose, 2016).

Identity Activation Interventions.

Other intervention studies have examined the link between anxiety and math performance by inducing or alleviating stereotype threat. Stereotype threat is the feeling of anxiety that an individual experience when they know that they are part of a group that is not expected to do well on a task (Spencer, Steele & Quinn, 1999). Women taking math courses, African Americans taking evaluative verbal tests, and white men who are told that their math performance will be compared to that of Asian men, have all been found to show performance deficits associated with stereotype threat (Steele & Aronson, 1995; Spencer, Steele & Quinn, 1999; Aronson et al., 1999). For example, in one study, white males were either given a math assessment and simply told that it was intended to measure their math ability (control condition), or first instructed to read articles about Asian students outperforming white students in math (stereotype threat condition) (Aronson et al., 1999). Those who read the articles were then told that they were taking a math assessment in order to help the researchers understand why Asian students outperform white students on math tests. The white males in the stereotype threat condition underperformed as compared to those in the control condition.

Similarly, when women are told that they are expected to perform worse than men on a math or spatial task, they have been found to underperform as compared to when they are told that they are expected to perform equally to or better than men (McIntyre, Paulson, & Lord, 2003; Moè & Pazzaglia, 2006). By selectively inducing or reducing the anxiety due to stereotype threat, the performance of a stereotyped groups can be improved or worsened.

Even activating one group identity over another can be an effective means of improving (or decreasing) performance. Ambady, Shih, Kim, & Pittinsky (2001) found that when Asian-American k-2nd and 6-8th grade girls were encouraged to think about their Asian identity by coloring pictures or taking surveys they performed better at math compared to a control condition. On the other hand, when they were primed to think about their gender identity by coloring pictures or answering surveys, they underperformed as compared to controls. These studies again indicate that anxiety, in these cases anxiety caused by stereotype threat, is associated with performance deficits, and that by alleviating stereotype threat and presumably anxiety, performance can be improved.

Writing Interventions.

Expressive writing interventions can serve to reduce the impact of anxiety on performance (Ramirez, & Beilock, 2011; Park, Ramirez & Beilock, 2014). For example, Ramirez and Beilock (2011) demonstrated that when individuals were allowed to express their anxiety through writing before a test in the lab or a high-stakes exam in a high school class, their performance on the test improved. In one study, they told participants that they would be paid if both they and an anonymous partner did well on a math test. The “partner” (who did not actually exist) was said to have already done well, leaving all of the pressure to perform and earn the money for both partners on the participant. Participants were also filmed and told that their performance would be viewed by students and teachers. After this pressure induction, Ramirez and Beilock (2011) assigned participants to either write for ten minutes about their emotions or sit silently, with both groups knowing that they would soon complete modular arithmetic problems. Participants who wrote about their thoughts and feelings regarding the test outperformed those in the control waiting condition.

A follow up study was conducted to see if the mere act of writing itself was enough to improve test performance, or if it was something about specifically writing about one’s emotions that gave students a performance boost (Ramirez and Beilock, 2011). In the lab, one group was asked to spend ten minutes writing about their daily lives, whereas another group wrote about their emotions about an upcoming math test. Those who wrote about their emotions, and specifically wrote about worries and negative thoughts, outperformed those in the active control condition. Thus, participants who engaged in expressive writing outperformed those who simply sat and waited for the test, and those who wrote about their daily lives instead of their feelings.

While some argue that writing interventions are effective because they allow people to organize their negative thoughts into a narrative structure and thereby come to terms with their emotions (Pennebaker, 1997; Pennebaker & Seagal, 1999), others posit that it is the mere act of expressing emotion externally that alleviates anxiety (Stucky & Nobel, 2010). To distinguish between these two competing possibilities, in Study 1, I investigated whether a drawing intervention, during which subjects draw a picture of their feelings before a math test, is as, or perhaps even more effective in improving math performance as writing about one's emotions before a test, with both conditions compared to a control condition. A drawing intervention allows people to express their emotions, without forming a narrative structure, which will provide evidence to distinguish between the two competing theories as to the mechanisms of writing interventions.

3.) What Does the Evidence from Studies of Pressure and Math Anxiety Reveal About How Parent Math Anxiety Relates to Child Math Performance?

In this section, I discuss the relation between parent math anxiety and child math performance, drawing attention to the gaps remaining in the literature with regard to the effect of pressure on parent instruction and the causal mechanisms of inter-generational effects of math anxiety. I then review the relation between teacher math anxiety and student math achievement, which has many similarities to the parent anxiety-child performance link.

Parent Math Anxiety and Child Math Performance.

As noted above, math anxiety is prevalent in the United States and around the world (Ashcraft & Kirk, 2001; Foley et al., 2017), and has consequences not only for those who experience math anxiety themselves, but also for the children of math anxious teachers and parents. Children with high math anxious parents learn less math over the course of the school year than their peers with low math anxious parents or teachers (Berkowitz et al., 2015; Maloney, Ramirez., Gunderson, Levine & Beilock, 2015).

One possible reason for this relation is that math anxiety is passed on from adult to child, and this anxiety subsequently harms child math performance. Indeed, a study of fifth to tenth grade children in India found that adult math anxiety and negative math attitudes were associated with child math anxiety and negative math attitudes, and this in turn was associated with poor math performance for children (Soni & Kumari, 2015).

Another, not mutually exclusive possibility, is that parent math anxiety harms child math learning by influencing home math interactions. For example, math anxious parents talk about number less often with their pre-school aged children (Eason, Nelson, Dearing, & Levine; under review). Yet it may not be enough to simply tell math anxious parents to do more math at home. In fact, the more frequently math anxious parents help their 1st - 2nd grade children with their math homework, the lower the child's math learning over the school year (Maloney et al., 2015). It could be that these homework interactions are high-pressure for high math anxious parents, and the demands placed on working memory resources preclude high quality math instruction.

To date there has not been a thorough investigation into, what, specifically, parents are doing during math interactions with their children that may lead to these intergenerational effects. There are many possibilities, including that high math anxious parents may be offering poor quality math instruction, thus failing to help, or even confusing, their children. It may be that because their working memory resources are depleted by their math anxiety, high math anxious parents may not be able to provide as effective math help compared to parents without this anxiety but with similar math knowledge (Ashcraft and Kirk, 2001; Beilock & Carr, 2005; Ramirez et al., 2016). This possibility has thus far not been investigated. In Study 2, I will investigate the specific features of parent-child math interactions that vary by performance pressure and parent math anxiety, in order to better understand the link between parents' anxiety and children's poor performance.

Teacher Math Anxiety and Child Math Performance.

We can also learn about the link between parent math anxiety and child math performance by studying a parallel link between teacher math anxiety and student math performance. Though teachers do not share a genetic link with the children in their care, teachers' attitudes influence student performance, suggesting that the behavior of adults during instruction may have important implications for child math performance. For example, Park et al., (2016) demonstrated that teacher's instruction impacted student's motivational frameworks. Students who have an incremental motivational framework of intelligence believe that intelligence is not fixed, and that increased effort can improve performance. Those with an entity framework, on the other hand, believe that intelligence is constant, and cannot be increased with effort. Park et al. (2016) found that teachers' instructional styles influenced children's motivational frameworks, which in turn were associated with children's performance.

Teacher math anxiety is another attitude that can impact student performance. In the United States, college students who are Elementary Education majors tend to be more math anxious than those in other majors, suggesting that many teachers may be suffering from math anxiety (Hembree, 1990). There is evidence that this impacts student math learning, with students whose teachers are higher in math anxiety showing less math growth over the course of the school year than those whose teachers are lower in math anxiety (Beilock et al., 2010). For example, Beilock, et al., (2010) found that elementary school girls show less math achievement growth across the course of the school year when they have a math anxious female teacher. In this 2010 study, the effect of teacher math anxiety on student math performance held only for girls and was mediated by girls' belief that boys are better at math than girls are. The authors speculate that having a high math anxious female teacher could convince young girls that math is a male subject, and thus harm their math growth. A more recent follow-up study (Schaeffer et al., under review) found that with a larger sample size, both boys and girls showed lower math achievement at the end of the school year when their teacher was high in math anxiety, indicating that high math anxious teachers may be harming the achievement of children in their class regardless of gender.

4) What Types of Interventions Have Thus Far Been Effective in Breaking the Relation Between Parent Math Anxiety and Child Math Performance?

In this section, I discuss the effectiveness of interventions designed to be used in the home to break the link between parent math anxiety and child math achievement and discuss future directions for these interventions.

Interventions in the Home.

One successful intervention was an iPad application called Bedtime Learning Together, which was given to parents and their first-grade children (Berkowitz et al., 2015). The app contains short passages and then a series of questions of different levels of difficulty that parents and children can solve together. Families were randomly assigned to receive either the math version of Bedtime Learning Together or a reading control version of the same app. At the end of the school year, children who received the math app were found to perform similarly no matter their parents' math anxiety level. Among the children who received the reading app, an achievement gap opened up, and by the end of the school year the children of high math anxious parents were performing significantly worse at math as compared to the children of low math anxious parents.

A follow-up study found that using the math app lessened the link between parent math anxiety and parents' expectations and valuing of math for their children, and that these positive expectations about their children's math achievement and their valuing of this achievement partially mediated the long term effectiveness of this intervention, years after parents had stopped using it (Schaeffer et al., 2018). It could therefore be high math anxious parents harm their children's math learning by not believing that their children are capable of high math performance, or that math is important for their children. This mechanism is consistent with evidence showing that utility-value interventions are effective in the home. For example, when parents of high school students were provided with a flyer and website explaining how math is relevant to various professions, the number of math courses that students took increased (Harackiewicz, Rozek, Hulleman, & Hyde, 2012; Rozek Svoboda, Harackiewicz, Hulleman, & Hyde, 2017). Furthermore, students' ACT scores in math improved in this intervention study. This again suggests that parents' low expectations and low valuing of math for their children is an avenue related to child math performance which can be intervened on in the home. It is also possible that by allowing parents to do math with their children in a low-pressure environment, the app reduced parent's negative feelings about math (Dowker et al., 2016). This in turn may have encouraged parents to do more math with their children in everyday contexts outside of using the app.

In study 3, I will test out this app intervention with a low-income sample to see if the app is effective at breaking the link between parent math anxiety and child math achievement in a population that has historically under-performed in math (Reardon, 2011; Larson, Russ, Nelson, Olson, & Halfon, 2015).

Future Directions

The series of studies that follow explore the ways in which math anxiety is related to lower performance on math tasks, lower ability to provide high quality math instruction, and interventions that may lessen this relation. Together, these studies explore the effects that math anxiety has on performance and instruction, and suggest ways to quantify, characterize, and address these relations. By developing support systems for math anxious students, parents and educators, I hope that these studies lay the groundwork for improved instruction in school and in the home, and also increase our understanding of the mechanisms that explain how math anxiety negatively impacts children's math learning.

STUDY 1: Can an art intervention lessen the relation between anxiety and performance at the individual level?

General Background

My first study investigates the socio-emotional factors that influence learning and performance at the individual level, testing out a potential intervention for later use in schools and homes (Herts, Chang, Beilock & Levine, 2018). Anxiety due to performance pressure or trait math anxiety can tie up working memory resources needed to perform complex tasks (e.g. Walker & Spence, 1964; Beilock & Carr, 2005; Herts & Beilock, 2017). Placing people under pressure, or studying them during everyday stressful situations, is a common way to investigate how state anxiety impacts performance and test out interventions to mitigate the effect of anxiety on performance. Furthermore, intervention studies offer some of the most compelling evidence that anxiety plays a causal role in these deficits. Many interventions that serve to offload anxiety before a test have been found to improve performance, especially for those who self-identify as anxious or have undergone a pressure induction (Beilock & Carr, 2005; Jamieson et al., 2016; Ramirez, & Beilock, 2011; Park et al., 2014).

One form of intervention that improves test performance are writing interventions, which involve writing about the feelings one is experiencing (Ramirez and Beilock, 2011; Park et al., 2014; Rozek, Ramirez, Fine & Beilock, 2019). For example, Ramirez and Beilock (2011) gave ninth grade students a writing intervention before a high-stakes biology exam at their school. Students who were anxious about tests and wrote about their feelings before taking the exam outperformed those who were told to think about something different than the exam. In a complementary lab study, college students underwent a pressure induction in which they were told that their performance on a math test would determine whether or not they and another individual received money. They were also filmed and told that their performance would be evaluated. Participants who wrote about their feelings before the test outperformed those who sat quietly or wrote about their daily lives. Furthermore, the proportion of the participants' sentences that expressed worries or negative thoughts accounted for the performance difference between the two conditions.

In a more recent writing intervention study, Rozek, Ramirez, Fine & Beilock (2019) tested an expressive writing intervention and arousal reappraisal intervention on ninth grade students before an important exam at their school. Arousal reappraisal involves re-interpreting physiological arousal such that a pounding heart or sweating hands are interpreted as a sign of preparedness and imminent success (Jamieson et al., 2010). To test the effects of expressive writing and arousal reappraisal, Rozek, Ramirez, Fine and Beilock (2019) assigned the students to engage in one of four activities: writing about their feelings, reading about arousal reappraisal, both writing about their feelings and reading about arousal reappraisal, or reading instructions to ignore their stress. Students who had the opportunity to engage in expressive writing, arousal reappraisal or both before a science exam at school outperformed those who were told to ignore their stress, an effect that was driven by the interventions' effectiveness for students from low-income families.

Though writing interventions like these have been shown to improve test performance, the mechanism by which writing may reduce anxiety is not entirely clear. Pennebaker (1997) posits that turning negative emotions into language is necessary to experience the benefits of expressive writing (Pennebaker & Seagal, 1999). Pennebaker and colleagues (Pennebaker, 1997; Pennebaker, Francis, & Booth, 2001) developed the Linguistic Inquiry and Word Count program (LIWC) in order to investigate words and linguistic features predictive of experiencing benefits from expressive writing. By analyzing writing samples from a series of six studies, they concluded that participants who benefited from expressive writing, compared to other participants, tended to use more words indicating positive emotions, a moderate (as opposed to low or high) number of words indicating negative emotions, and more cognitive causal and insight words (e.g. understand, because). They interpreted these findings as showing that the benefits of expressive writing can be attributed to developing a coherent narrative to cognitively process emotions.

An alternative theory is that expressive writing works because the act of expressing emotion itself reduces anxiety, even without a reflective, coherent, narrative structure (Pennebaker & Seagal, 1999; Stuckey & Nobel, 2010). This theory is supported by the literature from art therapy, which suggests that there are mental health benefits to creating any type of expressive art. For example, cancer patients (Geue et al., 2010) and trauma victims (Stuckey & Nobel, 2010), treated with art therapy, show a decrease in anxiety and depression. Furthermore, Coholic, Eys & Lougheed (2012) provide evidence that creating art about their emotions improves at-risk children's resiliency and self-concept. They tested eight to fourteen-year-old children who were referred by either a child protective agency or a mental health agency. In an art therapy intervention, the children explored their emotions and learned mindfulness by using art. The children explored their emotions through art, by, for example, drawing the world as an ant sees it, in order to explore others' perspectives, or creating collages about the emotions they experience in dreams. At the end of the study, these children exhibited improved self-concept and resilience as compared to business as usual control group and a group of children who learned traditional arts and crafts. These findings indicate that expressing emotions through art reduces the negative impact of trauma and stress.

The Current Study

Though we don't have direct causal evidence of how art therapy is effective, its efficacy is consistent with the theory that putting one's feelings down on paper can reduce the burden that anxiety places on working memory, by offloading the emotion (Geue et al., 2010; Stuckey & Nobel, 2010; Ramirez and Beilock, 2011; Coholic, Eys & Lougheed, 2012). This should be the case whether a coherent narrative is expressed or not. Therefore, we hypothesized that offloading emotion, with or without a narrative structure, would free up working memory recourses, allowing for better performance on cognitively demanding task problems. If anxiety ties up working memory, then expressing the anxiety in any form may free up working memory recourses that would otherwise be compromised. We hypothesized that the benefits of expressive writing are due to this mechanism, rather than from the process of developing a narrative to work through feelings and develop deeper insight.

To test these different theories, we placed participants in a stressful situation of having to take a test on difficult and unfamiliar math problems. Participants were randomized to draw a picture of their feelings (drawing condition), write about their feelings (writing condition), or simply sit and wait (control condition) before taking the test. Waiting to perform a difficult or unpleasant task has been shown to cause anticipatory anxiety (Berns et al., 2006), and is associated with anxious behavior, and cardiovascular symptoms including increased heartrate (Grupe & Nitschke, 2013; Waugh, Panage, Mendes, & Gotlib, 2010). For example, when math anxious people wait to solve math problems, they show activation in areas of the brain associated with pain (Lyons & Beilock, 2011). Therefore, we expected those in the control condition to experience pressure from having to simply wait. Those in the drawing and writing conditions would have the opportunity to offload that anxiety through expressing their emotions.

If the drawing intervention were successful in improving test performance, that would provide evidence that it is the expression of emotions, rather than the narrative structure of a paragraph, that frees up working memory and improves performance. Drawing may also be a particularly effective intervention for students who feel anxiety about writing or are too young to be able to write well. In addition to clarifying the mechanism by which offloading anxiety improves performance, this study provides a foundation to develop concrete ways to help math anxious people succeed when faced with stressful testing situations, and perhaps also during math instruction.

Though our main research question concerned the overall effect of interventions on math performance, we also explored whether the effectiveness of the interventions varied as a function of participants' math anxiety. Therefore, we sought to discover if those in the writing and/or drawing intervention would outperform those in the control condition and if high math anxious participants would underperform on a math task compared to low math anxious participants.

Methods

Participants

We tested 110 adult participants at the University of Chicago, ranging in age from 18 to 32 years with a mean age of 21.07. Participants were assigned to condition randomly within each block of gender. Two participants were excluded from analyses due to technical difficulties which led to their data not being recorded. Two other participants were erroneously tested twice, and their second session was excluded from analysis. Our 106 remaining participants consisted of 36 participants in the drawing condition (25 female, 11 male), 35 participants in the control condition (24 female, 11 male) and 35 participants in the writing condition (23 female, 12 male).

Procedure

Participants filled out surveys before coming in to the lab, including a trait math anxiety survey (sMARS; Alexander & Martray, 1989) and demographic questionnaires[1]. At the very end of the experiment, participants filled out a second survey which included a state anxiety survey (STAI; Spielberger, 1983) and reported on how much performance pressure they felt while solving the math problems on a scale from 1 to 7 (Beilock, Kulp, Holt & Carr, 2004). One participant in the control condition did not take the post-test survey due to experimenter error.

The experiment was conducted using EPrime. Participants read a brief math lesson on modular arithmetic. Modular arithmetic problems are written in the form x = y (modz), and solved by subtracting y from x, and then dividing that difference by z. If the final answer has a remainder it is false, while if there is no remainder it is true. Participants pressed keyboard keys to indicate a true or false answer for each problem. There were two types of modular arithmetic problems: those that were more difficult and placed a **high demand** on working memory resources, and those that were less difficult and placed a **low demand** on working memory resources. For example, one of the low demand problems was 8 = 5 (mod3), while one of the high demand problems was 83 = 27 (mod8). Modular arithmetic is the same task that has been using in previous writing intervention studies (Ramirez, & Beilock, 2011). Participants tend to be unfamiliar with the task, while at the same time it can be taught quickly in a laboratory environment.

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[1] One participant filled out the pre-lab survey twice in a row on the same day, and for that participant we used the first survey they filled out. Four other participants filled out the pre-lab survey more than once before coming in to the lab, but with a long delay between the first and second time they filled out the survey. Because there was often a gap of months between survey completion dates, we used the survey that was completed closest to the date that the participant came in to the lab for these four individual. That way, if their feelings, opinions, or demographic situation had changed between the two surveys we had the most up to date information.

After completing eight practice problems with feedback, participants then waited for seven minutes before being tested on eighty modular arithmetic problems. During that wait time, participants were randomly assigned to either wait silently (control condition), write about their emotions (writing condition), or draw a picture of their emotions (drawing condition). Those in the experimental conditions were given paper instructing them to either write or draw an image with no words that expressed their thoughts and feelings regarding the math problems they were about to solve. Those in the control condition were given paper instructing them to wait, and they sat and waited for seven minutes. See Appendix for the specific prompts used.

Results

Descriptive Statistics

Average performance for the control condition on the Low Demand problems ranged from 90 to 100% (M= 97.21, SD= 2.69) and on the high demand problems ranged from 48% to 100% (M=81.71, SD=13.60). For the drawing condition, average score on the Low Demand problems ranged from 85% to 100% (M=96.94, SD=3.11), and on the high demand problems ranged from 60% to 100% (M=89.72, SD=8.38). For the writing condition, average score on the Low Demand problems ranged from 83% to 100% (M=97.21, SD=3.73) and on the high demand problems ranged from 68% to 100% (M=85.57, SD=7.95).

Independent sample t-tests revealed that the groups did not differ significantly by condition with regard to their trait math anxiety scores, reported pressure felt during the study, or their state anxiety reported immediately after the study (see Table 2). Across all conditions, math anxiety as measured by a sum of responses on the sMARS, ranged from 0 to 83 (M=38.37, SD=19.572), performance pressure ranged from 1 to 6 (M=3.96, SD=1.45), and state anxiety measured by a sum of responses on the STAI ranged from 20 (the lowest possible score) to 69 (M=28.35, SD=10.849). As shown in Table 1, math anxiety was directionally higher in the writing condition than the other two, however this difference was not statistically significant, as shown in Table 2.

Table 1. Descriptive statistics by condition

Condition	Measure	Minimum	Maximum	Mean	Std. Deviation
Control	Math Anxiety	8	71	37.66	17.93
	Reported Pressure	1.00	6.00	3.6857	1.45
	State Anxiety	2.44	3.72	3.0794	0.35
Drawing	Math Anxiety	6	83	35.28	19.88
	Reported Pressure	2.00	6.00	4.1667	1.40
	State Anxiety	1.83	3.61	2.9306	0.47
Writing	Math Anxiety	0	81	42.26	20.70
	Reported Pressure	1.00	6.00	4.0286	1.48
	State Anxiety	2.06	3.61	2.9636	0.41

Table 2. Independent t-tests of survey results between conditions.

	Math Anxiety	Reported Pressure	State Anxiety
Control vs Drawing	t = .529, p = .598	t = -1.343, p = .184	t = -1.685, p = .097
Control vs Writing	t = -.994, p = .324	t = -.908, p = .367	t = -1.392, p = .169
Drawing vs Writing	t =-1.449, p = .152	t = .403, p = .688	t = .377, p = .707

Trait math anxiety and reported pressure were correlated with one another r(105) = .260, p = .007. Math anxiety and state anxiety were correlated at r(105) = .484, p = .000, and state anxiety and reported pressure were correlated at r(105) = .316, p = .001

Analyses

Regressions.

Math anxiety scores were transformed into z scores in order to find the relative math anxiety of the sample. For all models, the outcome variable was accuracy on the high demand problems, which we expected to be most compromised by the effect of anxiety on working memory (Beilock & Carr, 2005; Park et al., 2014). Please see Table 3 below for full descriptions of all models and results. Because high demand problem accuracy is most compromised by demands on working memory due to pressure or anxiety, we only expected math anxiety and condition to be significantly predictive of accuracy on the high demand problems. Indeed, neither variable significantly predicted performance on the low demand problems.

Table 3. Regression model descriptions

Model		Unstandardized Coefficients	Standardized Coefficients	t	Sig.
1	(Constant)	0.816 (.017)		48.450	0.000
	Drawing vs. Control Contrast	0.077 (.024)	0.341	3.241	0.002 *
	Writing vs. Control Contrast	0.045 (.024)	0.199	1.881	0.063
	Z Score of Math Anxiety (zMA)	-0.027 (.010)	-0.256	-2.784	0.006 *
2	(Constant)	0.816 (.017)		48.611	0.000
	Drawing vs. Control Contrast	0.074 (.024)	0.328	3.115	0.002 *
	Writing vs. Control Contrast	0.041 (.024)	0.182	1.720	0.089
	Z Score of Math Anxiety (zMA)	-0.030 (.019)	-0.277	-1.597	0.113
	zMA x Writing vs. Control Contrast	0.022 (.025)	0.125	0.895	0.373
	zMA x Drawing vs. Control Contrast	-0.017 (.025)	-0.092	-0.668	0.506

Outcome Variable: High Demand Problem Accuracy * p<.05

Model		Unstandardized Coefficients	Standardized Coefficients	t	Sig.
3	(Constant)	0.893 (.017)		53.536	0.000
	Control vs. Drawing Contrast	-0.077 (.024)	-0.339	-3.241	0.002 *
	Writing vs. Drawing Contrast	-0.032 (.024)	-0.140	-1.328	0.187
	Z Score of Math Anxiety (zMA)	-0.027 (.010)	-0.256	-2.784	0.006 *
4	(Constant)	0.890 (.017)		53.150	0.000
	Control vs. Drawing Contrast	-0.074 (.024)	-0.326	-3.115	0.002 *
	Writing vs. Drawing Contrast	-0.033 (.024)	-0.144	-1.366	0.175
	Z Score of Math Anxiety (zMA)	-0.046 (.017)	-0.432	-2.803	0.006 *
	zMA x Writing vs. Drawing Contrast	0.039 (.023)	0.220	1.674	0.097
	zMA x Control vs. Drawing Contrast	0.017 (.025)	0.081	0.668	0.506

Outcome Variable: High Demand Problem Accuracy * p<.05

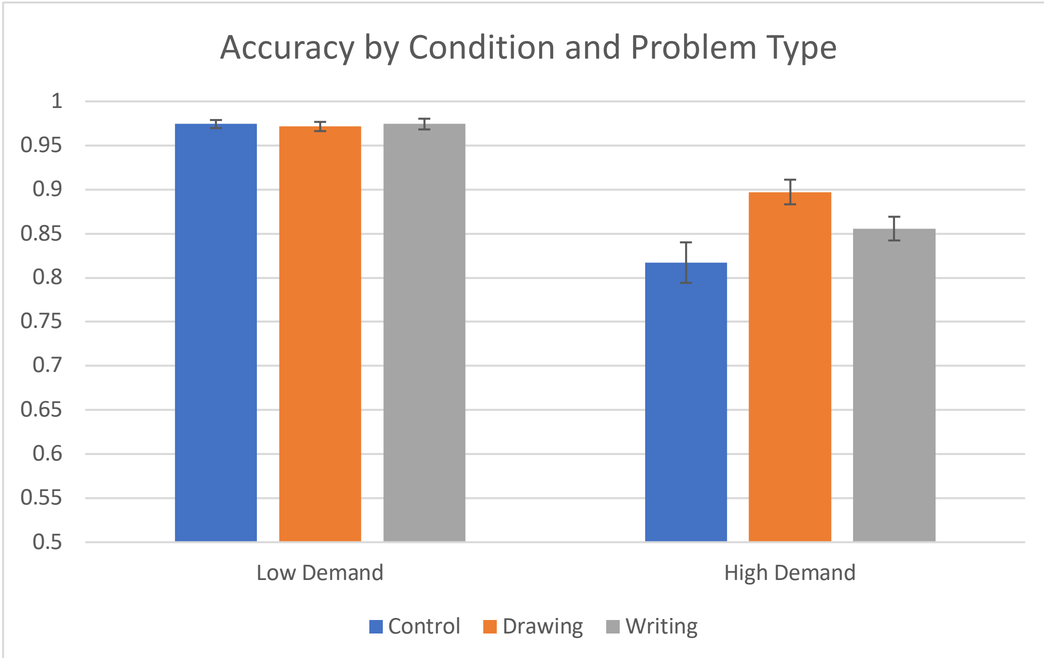


Figure 1. Math problem accuracy by condition and problem difficulty.

In Model 1, dummy codes were used in order to compare the effects of being in each experimental condition to the control condition. For the drawing condition dummy codes, the drawing condition participants were coded as 1, while the control and writing condition participants were coded as 0. For the writing condition dummy codes, the writing condition participants were coded as 1, while the control and drawing condition participants were coded as 0. This allowed us to compare the effect of being in the drawing condition and the effect of being in the writing condition to the baseline of being in the control condition. The independent variables were the condition contrasts and math anxiety score. There was a main effect of math anxiety, such that those who were higher in math anxiety performed worse on the high demand problems. There was also an effect of being in the drawing versus control condition, with those in the drawing condition outperforming those in the control condition.

In Model 2, we set out to discover if there was an interaction between math anxiety and the drawing versus control condition, as we had found main effects of each in Model 1. In this model we found a simple effect of being in the control versus drawing condition. We found no simple effect of math anxiety, and we did not find a significant interaction between math anxiety and the drawing versus control contrast.

In Model 3, we examined whether there was a difference in performance between the two intervention conditions. For this model, dummy codes were used again. For the writing condition dummy codes, those in the drawing and control condition were coded as 0, the writing condition participants were coded as 1. For the control condition dummy codes, participants the control condition participants were coded as 1, and those in the writing and drawing conditions were coded as 0. This allowed us to compare the effect of being in the writing condition and the effect of being in the control condition to the baseline of being in the drawing condition.

There was again an effect of math anxiety on performance on the high demand problems, but no effect of being in the drawing versus the writing condition. In Model 4, when the interaction terms were added in, we again found no interaction with the dummy coded conditions and math anxiety. There were again simple effects of math anxiety and the control versus drawing dummy[2].

[2] Accuracy scores for the high and low demand problems are decimals representing a percentage out of 100. I am using this outcome measure because percent accuracy is a common outcome measure (Park, Ramirez & Beilock, 2014; Rozek, Ramirez, Fine & Beilock, 2019) and best represents the actual data collected (Osborne, 2002). Some argue that all proportion and percentage data should be transformed (Howell, 2013). Here I report the result of doing so. Log transformations are most appropriate for positively skewed data. Since some participants got 100% correct, and nobody got 0% correct, I reversed the direction of the data by taking each percent correct and subtracting it from 101 (instead of 100 so that nobody would score 0). Therefore, somebody who scored 80% correct would have a transformed score of 21. A natural log transformation on this reversed data revealed the same pattern of significance as the untransformed data, with one exception. In the fourth model, the marginal interaction between

Power Analysis.

Using G*Power, I conducted a power analysis for the linear regression in Model 2, which examined the effects of each intervention condition, math anxiety, and the interactions between the interventions and math anxiety on the outcome variable of High Demand Problem Accuracy. I found that with a medium effect size of $f^2 = .15$ (Cohen, 1988), the study could achieve power of .80 with 92 participants. This study had 106 participants. Therefore, this study had a large enough sample to detect an effect.

Discussion

Our results suggest that expressing emotion in non-narrative form can improve math performance. We also found a main effect of math anxiety, with high math anxious participants underperforming compared to low math anxious participants.

In Model 1, we found that those in the drawing condition outperformed those in the control condition. Thus, we found that a drawing intervention, during which subjects draw a picture of their feelings before a math test, is effective at improving math performance on difficult math problems (see Figure 1). This is consistent with the idea that it is the offloading of emotions, rather than the formation of a narrative structure, that frees up working memory and improves math performance (Stuckey & Nobel, 2010). Anxiety can interfere with cognitive resources such as working memory, and downloading anxiety via drawing, like other ways of

math anxiety and being in the writing vs. drawing condition crossed into significance with B = -.92, t = -2.248, p = .027 such that there was a smaller gap between the performance of high and low math anxious individuals in the writing condition than in the drawing condition. There is no main effect difference between the writing and control groups or writing and drawing groups using either the raw or transformed data, so caution should be used when interpreting this interaction.

downloading emotion highlighted in prior studies, can free up these resources, which in turn allows students to perform at higher levels on assessments.

In Model 1, we also found that those in the writing condition did not significantly differ from those in the control condition (the effect was marginal), while in model 3, we found that performance in the writing condition also did not significantly differ from performance in the drawing condition. These results indicate that performance in the writing condition was intermediate between control and the drawing condition. Therefore, we did not find that the writing intervention was more effective than the control condition, as has been found in previous studies. Importantly, the writing condition was also not significantly different from the drawing condition, which did significantly differ from control.

In Model 2, we did not find a significant interaction between math anxiety and being in the drawing condition versus the control condition, indicating that the intervention was effective for both the high and low math anxious. This is consistent with some previous research finding no interaction between trait and state anxiety on task accuracy (Taylor, 1958; Pacheco-Unguetti Acosta, Callejas, & Lupiáñez, 2010; Park e al, 2014), but inconsistent with a previous writing intervention which found expressive writing to be especially helpful for those higher in math anxiety when the outcome was a composite of error rate and reaction time (Park et al., 2014). This is perhaps not surprising, given that the current study also did not replicate the prior study's main effect of those in the writing condition outperforming those in the control condition. However, our findings suggest that offloading emotion through drawing may be effective across the anxiety spectrum, unlike previous writing interventions (Ramirez & Beilock, 2011; Park et al., 2014).

Future studies better balanced in math anxiety across condition, can further examine this possibility. Further, individual variations in the helpfulness of different ways of offloading emotion need to be explored. Perhaps for some individuals writing helps them to process through their emotions, while for others, it leads to rumination that exacerbates the anxiety (Mesghina & Richland, 2019). For these folks, drawing's lack of inherent narrative structure may be more helpful.

One limitation of this study is we did not find that participants in the control condition reported more performance pressure or state anxiety than those in the intervention conditions. Thus, it could be that simply waiting to perform math problems did not induce enough pressure on participants to make the interventions effective at changing the amount of pressure felt. Future studies that induce more pressure may find stronger results, including a significant interaction with math anxiety. This could also be the reason that we found a marginal, rather than significant, difference between the writing condition and the control condition. If writing is an effective intervention because it reduced anxiety, and participants were not anxious enough to need their anxiety reduced, this could explain the lack of performance difference between the control and writing conditions. A follow-up study that uses a stronger pressure induction, perhaps by filming participants and telling them that their performance will determine whether or not they and a partner receive money (as in Ramirez & Beilock, 2011), may find a significant difference between the writing and control conditions, and perhaps an even larger difference between the drawing and control conditions than the one found in the current study.

Future studies could also use a larger sample size to examine which aspects of a drawing may be associated with improved performance. With more participants in each condition we would be able to better divide the drawing and writing samples into categories based on their content. It is possible that participants who use more narrative features in their drawings (e.g. arrows connecting aspects of the drawing), or more imagery concerning emotions may most benefit from the intervention (Pennebaker, 1997; Park, Ramirez, and Beilock, 2014). It is also worth exploring whether drawing may for some individuals reframe negative emotions into absurd or humorous ones (Abel & Maxwell, 2002; Jamieson, 2010), given that in our small sample four of the participants in the drawing condition drew humorous images (e.g. a very dramatic face screaming or somebody hiding from a number). Perhaps by making their fear funny these participants were able to better regulate or reinterpret their emotions. The drawing and writing samples from this or a future study could be analyzed to examine whether the use humor, a narrative structure, or words associated with worries and negative thoughts (as in Rameriez & Beilock. 2011) are associated with enhanced performance. A thorough examination of the drawings and writings produced in this and other studies could shed light on this issue.

Better understanding the current intervention could lay the groundwork for studies of its efficacy in schools and in the home. The anxiety that people feel when they are about to take a difficult math test may well be similar to the way that high math anxious parents and teachers feel when they sit down to teach math to children. Using interventions like drawing before helping a child with math homework may help parents free up their working memory resources, and thus have a better experience teaching their child math. Drawing interventions may also work for math anxious children, helping them to break the link between anxiety and poor performance at ages when they are not able to write about their emotions in an effective manner.

The results of this study provide evidence concerning a debate in the field about how exactly emotional expression impacts anxiety (Pennebaker, 1997; Stucky & Novel, 2010). They also provide a jumping off point to further investigate the impact of drawing interventions on working memory and performance, how drawing versus writing may vary in effectiveness depending on the age of participants, and their confidence with drawing versus writing. Finally, these results may contribute to the development of new interventions for math anxiety, which could be useful to a broad range of individuals, both across age and across home and school contexts.

STUDY 2: How and why does parent math anxiety relate to child math achievement?

General Background

Children with high math anxious parents show less math growth over the course of the school year than their peers with low math anxious parents (Berkowitz et al., 2015). This could be at least in part because parents' math anxiety influences parent/child math interactions in the home, and this in turn impacts children's math learning (Maloney et al., 2015; Berkowitz, Gibson & Levine, under review). For example, Maloney et al. (2015) found that when high math anxious parents more often helped their children with math homework, the children learned less over the course of the school year. Yet the specific ways that parent math anxiety impacts homework help, and other home math interactions, has received little attention. How do high and low math anxious parents differ in the type of support that they provide to their children during home math interactions? Answering this question could help us to understand how math anxiety impacts parent behavior, and how that behavior in turn impacts children's learning. In this chapter, I explore the means by which high math anxious parents negatively impact their children's learning in a novel study in which I code parent-child math interactions. I investigate how math anxiety is related to parents' support of their children's math by examining parent-child math interactions during high- and low-pressure math activities.

One possibility is that high math anxious parents provide lower quality instruction to their children than low math anxious parents do. There are many reasons that this may be the case. Math anxious parents may experience working memory deficits associated with anxiety, making it difficult to explain the material to a child, especially a child who struggles to understand the material (Beilock & Carr, 2005; Herts & Beilock, 2017). Additionally, math anxious parents who have avoided math may feel less familiar and comfortable with the math material that they engage in with their child (Hembree, 1990; Chinn, 2012; Choe, Jenifer, Rozek, Berman & Beilock, 2019). Even if a high math anxious parent knows one way to solve a problem, they may not have a solid enough grasp of the subject to flexibly meet their child at the appropriate level of understanding and provide appropriate support. Finally, math anxious parents may be afraid that their child will experience negative emotions due to math and feel the urge to be intrusive in order to spare their child from suffering from anxiety (Stigler & Hiebert, 1999). Any or all of these explanations may account for observed differences in instruction associated with parent math anxiety.

In the current study we take a first step in examining how parent support of their children during math activities differs as a function of their own math anxiety. Identifying these differences lays an important foundation for future work aimed at identifying the specific causes of these differences, as well as studies that aim to test interventions that hold potential for helping parents provide more effective math support to children.

To see if high and low math anxious parents provided different support, in the current study we video-taped parents and children completing age-appropriate math problems together. We coded their interactions using two different coding schemes. In one scheme, we rated the quality of the math instruction that parents provided to their first-grade children on a scale of teaching quality (Herts, Beilock, and Levine, 2019). Using a second coding scheme, we counted the number of times the parents engaged in certain behaviors that we hypothesized might vary with math anxiety.

Pilot Studies

The current study was a replication and expansion of two previous studies, which developed and tested coding schemes designed to measure how parent-child math interactions varied, and whether these variations were related to parent math anxiety. Below, I briefly describe each of these two pilot studies in turn.

Pilot Study 1: Modified Reform Teacher Observation Protocol

As discussed above, Berkowitz et al., (2015) found that the Bedtime Learning Together app helped to reduce the achievement gap between the children of high and low math anxious parents compared to a control group who received a similar app that focused on reading comprehension. Yet, based on previous literature demonstrating that math anxious individuals struggle with math (Ashcraft, 2002), we hypothesized that high math anxious parents may offer less effective math support to their children even in this ideal, scripted, low-pressure situation.

For this pilot study, as described in Herts, Beilock and Levine (2019), we coded 29 videos of parents (76% female) doing the math ipad application (Bedtime Learning Together, or BLT) with their first-grade children in their homes. Parents were instructed to use the app with their children the same way they ordinarily would, as if the observer and camera were not there. We focused on two age-appropriate math problems, one from each of two passages that parents and children worked on together.

Videos were coded using six items adapted from the Reform Teacher Observation Protocol (RTOP; Piburn et al., 2000; Sawada et al., 2002), which is a scale designed to rate classroom teachers. The RTOP was created by the Arizona Collaborative for Excellence in the Preparation of Teachers (ACEPT), specifically to encourage best teaching practices. The RTOP is a 25-item scale that aims to measure the extent to which teachers are using reform practices in their teaching by letting the child take the lead and construct their own knowledge (Kilday & Kinzie, 2008). Importantly, teaching practices included in the RTOP are correlated with student growth in math and science classes (Sawada et al., 2002; Hamilton et al., 2003; Roehrig, Kruse & Kern, 2006) Using modified items from this scale, we aimed to test our hypothesis that high math anxious parents would be less effective in teaching their children math than low math anxious parents.

The RTOP is used a full instrument composed of various subscales (Piburn et al., 2000). In choosing which items from the full RTOP scale to use, we selected the six items from across the various subscales that best applied to parent/child math interactions. We also aimed to select items that captured a variety of facets of the interaction and avoid redundancy in the selected items. Any item that referred to the design of the lesson was not selected, as the parent did not design the lesson themselves. Similarly, any item that involved managing interactions between multiple students was not selected. The items were modified in order to make them refer to parents and children, instead of teachers and students and to more clearly apply to the parent/child situation.

The final items were:

1. The instructional strategies respected the child's prior knowledge and preconceptions.
2. Parent provided opportunities for child exploration before instruction.
3. The parent's instruction promoted coherent conceptual understanding
4. The parent had a solid grasp of the subject matter content inherent to the problem
5. Child was actively engaged in critical thinking.
6. In general, the parent was patient with the child.

Items 1, 2, and 3 were adapted from the Lesson Design and Implementation subscale. Items 3 and 4 were adapted from the Content-Propositional Knowledge Subscale, Item 5 was adapted from the Content-Procedural Knowledge Subscale and Item 6 was adapted from the Classroom Culture- Student/Teacher Relationships subscale. No items were adapted from the Classroom Culture-Communicative Interactions subscale, which concerned students' interactions with each other.

Items were each coded on a 0-4 scale (see Appendix for coding details). In this pilot study, through a linear regression, we found that parents' scores on this modified RTOP scale were negatively related to parent math anxiety (as measured by the sMARS; Alexander & Martray, 1989), β =-.474 t=-2.794, p=.009, even controlling for parents' Woodcock Johnson Math Fluency score (Woodcock, McGrew, & Mather, 2001), and children's Woodcock Johnson Applied Problems scores (β =-.368 t=-2.142, p=.042).

This pilot study provided insight into the nature of the differences between the math support provided to children by high and low math anxious parents. High math anxious parents were found to score lower on our scale encompassing the extent to which they were adept at respecting child's prior knowledge, providing opportunities for exploration, promoting conceptual understanding, understanding the math content, and critical thinking, and being patient.

Pilot Study 2: Specific Supports that Parents Provide Children During Math Tasks

In a second pilot study, we looked more closely at the specific kinds of support that high and low math anxious parents were giving their children (as described in Herts, Bernett, Lawlor, Beilock, et al., 2019, and Herts, Bernett, Lawlor, Kazi, et al., 2019). This study was part of a larger longitudinal study, in which children were observed first as toddlers, and then throughout their childhoods and adolescence (Goldin-Meadow et al., 2014). The data used in this study was collected when children were in 7th grade.

50 parents (90% of whom were female) and children were filmed doing tasks together in their homes. Among the tasks that parents and children completed were three math asks, and three art tasks. We coded the frequency with which parents and children exhibited particular behaviors during each type of task. Specifically, we counted each time a parent or child offered a new strategy to solve a problem, disagreed with the other member of the dyad (with and without explaining why), explained a concept, expressed confusion, said something emotionally valanced about math, or offered an intermediate or overall solution to the problem.

We analyzed this frequency data using Bayesian statistics. All models controlled for parent gender, child gender, child math ability, family SES, and child math anxiety (as measured by the sMARS; Alexander & Martray, 1989). We found that, compared to lower math anxious parents, higher math anxious parents suggested a smaller proportion of the strategies that the dyad used while solving the math tasks, (95% Highest Posterior Density Interval: -0.72 to -0.13 on a logit scale) but not the art tasks, and that this difference between the math and art tasks was reliable (95% HPDI: -0.70 to -0.05). Furthermore, there was a trend by which higher math anxious parents disagreed with their child less often during the math tasks, but not the art tasks and this difference between the two tasks was reliable (95% HPDI: -0.69 to 0.01). Finally, there was a trend in which higher math anxious parents expressed confusion more often than lower math anxious parents in the math, but not the art tasks (95% HPDI: 0.05 to 1.34). We did not find differences by parent math anxiety with regard to the number of times that parents offered explanations or solutions, nor the number of negative remarks that they made about math.

In this study, we again found that parent math anxiety was related to parent/child math interactions. Specifically, we found that when interacting with older children, on harder math problems, higher math anxious parents provided less support than lower math anxious parents. They offered a smaller proportion of the strategies the pair used, less often contradicted their child, and more often said that they were confused.

Current Study

These pilot studies provide insight into how individual differences in parents' math attitudes relate to their math support, shedding light on how variations in math achievement may arise. In the current study, we sought to replicate these two studies by using both coding schemes on one set of videos of parent/child math interactions. Using these two coding schemes gave us a look at both the general and specific features of parent/child math interactions that vary by parent math anxiety. Furthermore, it allowed us to see if the results of these two pilot studies held in a larger sample, and to examine whether these two ways of measuring parent math support are related to each other.

The current study also sought to investigate the effects of high parent math anxiety during math interactions that were specifically designed to either enhance or mitigate the amount of pressure that parents were feeling. To do this, we implemented a pressure manipulation, in order to make some parent/child dyads feel that the math interaction was high stakes.

Based on the results of our pilot studies, we hypothesized that high math anxious parents would interact differently with their children while solving math problems than low math anxious parents. Specifically, we hypothesized that high math anxious parents would do a worse job teaching math content to their children compared to the low math anxious parents as measured by the modified RTOP scale. Using the more specific coding scheme, we hypothesized that higher math anxious parents would again be less responsive to their children, offering fewer strategies and disagreeing less often with their children. Additionally, we hypothesized that no matter their level of math anxiety, parents placed under pressure would exhibit inferior quality teaching and would be less supportive when interacting with their child.

Differences we find between the math support that high and low math anxious parents provide children in this laboratory study, may reflect differences that occur during math homework interactions at home. That is, if more math anxious parents provide less effective math support, this may lead their children to be confused about math concepts and procedures, and perhaps lead them to develop lower confidence in math and ultimately more math anxiety, contributing to a vicious cycle of lower math knowledge and less adaptive math attitudes reinforcing each other (Gunderson et al., 2018). We set out to discover if there are observable differences in the way that high and low math anxious parents interact with their children when doing math problems together while under pressure and in a more relaxed environment.

Methods

Participants

Original Sample.

The families recruited for this study were a subset of those participating in a larger survey study. All of the primary caregivers who were recruited for this sub-study were female and able to understand English. Families with children in first to second grade were recruited, with children coming in to the lab the summer before they started first grade, during first grade, the summer before second grade, or during second grade (Henry, 2017).

183 parent-child dyads participated in the in-lab portion of the larger study. 25 dyads who were run were excluded from analysis for the following reasons: 5 had already participated in the study or a pilot version of it, for 10 there were technical difficulties that led to their session not being recorded, for 3 we had no math anxiety or other behavioral measures for the parent who participated because another family member filled out the survey, 3 never saw the task instructions, 2 were accidentally shown the instructions for the wrong condition, 1child withdrew assent to participate, and 1 had a parent who conducted research in our lab and therefore knew too much. These exclusions left us with an initial pool of 158 parent-child dyads. The children were 88 girls and 70 boys, with 79 in each condition.

Coding Sample.

For this study, we analyzed a subset of 89 parent-child dyads due to time constraints. Due to an initial plan to code all of the 158 videos, the first 13 videos coded over-represent those who came into the lab towards the beginning of the study. We also included all of the usable videos where the parent had a math anxiety score of 4 or higher as measured by the sMARS, which was 4 videos, in order to ensure that we had enough of a range of parent math anxiety. The rest of the videos in the sample were randomly selected within condition and child gender in order to have roughly equal numbers of boys and girls in each condition.

Throughout the coding process, we discovered more videos that were not usable, and these videos were excluded and replaced with another randomly selected video in the same condition and with a child of the same gender. Four videos that were initially selected were replaced because the parent spoke in a foreign language to the child and could not be understood by the coders. One was excluded and replaced because the parent was not comprehensible.

Additionally, one video was excluded after coding was complete because the parent and child did not sufficiently complete the task. They showed no work and got every problem wrong. This video was not replaced, as it was not discovered until after coding was completed.

Our final sample includes 89 of the 158 parent/child dyads who came in for the study. The final sample of 89 videos includes 45 in the control condition, and 44 in the pressure condition, with 21 boys and 24 girls in the control condition and 21 boys and 23 girls in the pressure condition.

In terms of demographic characteristics, this sub-sample was similar to the sample of 158. In our sample, 88 of the 89 parents reported their children's ages, which ranged from 5.83 years to 7.83 years, with a mean of 7.19 years, and a standard deviation of 4.65 months. This is very similar to the original sample, which ranged from 5.83 to 9.08 (this oldest child was more than 3 standard deviations from the mean age). The mean age of the children in the original sample was 7.20 (SD = 5.22 months). Parent math anxiety in our sample as measured by the sMARS in our ranged from 1 to 4.52 (M = 2.26, SD =.87). This again is very similar to that of the original study, in which Parent Math Anxiety ranged from 1 to 5 (M = 2.23, SD = .86).

Procedure

Other Tasks and Surveys.

Although many measures were collected on these participants, and many are potential variables of interest, I focus specifically on the parent-child math task and its relation to parent math anxiety and condition, but provide a brief description of all tasks that were given to parents and children as well.

Parents filled out a survey before coming into the lab as part of the larger survey study that they participated in. Among the questions asked in the survey were the sMARS math anxiety questionnaire (Alexander & Martray, 1989), questions about homework help, and demographic questions. In the lab, parents and children completed several more tasks. First, parents completed a Stroop task to measure executive function (Golden & Freshwater, 1978). Children completed a math anxiety survey (Ramirez, Gunderson, Levine & Beilock, 2013), as well as a forward and backward letter span task and solved six math word problems. Then the parent and child were filmed doing math problems together, as described below. After the filmed parent-child math task, the children completed the Applied Problems subset of the Woodcock Johnson Tests of Achievement (Woodcock, McGrew, & Mather, 2001) and completed a survey about their attitudes towards math and the pressure that they felt during the parent/child math activity. Then parents filled out another survey, which included questions about their expectations and values of math for their child questions, pressure questions about the task that they completed with their child (Beilock & DeCaro, 2007) and state anxiety questions (STAI-S; Speilberger, 1983). The parent performed the executive function Stroop task again, and then completed modular arithmetic problems. The parent then filled out a final survey which included questions about their relationship with their child.

The Parent-Child Math Task.

Once in the lab, parent-child dyads were randomly assigned to either a pressure or a control no-pressure condition blocked by child gender. The parents and children all watched a video before they started doing math problems together. In the pressure condition the video told them the problems were like homework and would be graded, and that the parents would be given feedback based on their child's performance. In the non-pressure condition the video said that the answers would not be checked, and we were only interested in the general interaction (See Appendix for specific instructions). All parent-child dyads were then told that they would spend 10 minutes solving problems. Additionally, in the non-pressure condition the sheet with the problems on it showed the answers. The problems that the parent and child solved together were created for this study and designed to be age appropriate (See Appendix).

General Coding Methods

The problem sheet that the participants received contained 10 labelled math exercises. Three of the exercises had multiple parts which asked different questions, and we counted these as separate problems. This left us with a total of 15 problems that the parent and child could solve.

Each problem was coded separately. When a problem was skipped, or the child immediately said the answer with no input from or discussion with the parent, the problem was not coded or counted. Incomplete problems were also not coded. A problem was counted as incomplete if the dyad did not completely finish it and move on to the next problem. We created this criterion to reduce ambiguity and so that we were coding the complete interaction for each problem for each family. There were two coders, each using a different coding scheme. They resolved disagreements as to the number of problems that should be coded for each family through discussion. The coders were blind to the fact that there was a pressure and non-pressure condition, and while they inevitably saw that some families had the answers and others did not, they did not know why. They were also blind to all other information about the dyads, including their math anxiety levels and performance on any other tasks.

Coding Methods for the Modified RTOP Scale

To support the broad hypothesis that high math anxious parents would provide lower quality explanations we developed a coding scheme using items from an existing teacher evaluation scale, the Reformed Teacher Observation Protocol (RTOP; Sawada, 2002). The coder rated each problem that the participants solved on a scale from 0 to 4, using a coding guide that was initially developed during the pilot study described above. The six items concern having respect the child's prior knowledge, providing opportunities for the child to explore the problem, promoting conceptual understanding, understanding the math content, promoting critical thinking, and being patient. A second coder obtained reliability on a subset of 18 (20.2%) of the videos, ICC (2, 1) = .856 (Koo & Li, 2016). Coders were not reliable at the item level, only on the overall standardized composite average, which as described in the results section, was the unit of analysis.

Coding for Specific Parent Supports

To investigate the hypothesis that high math anxious parents would be less responsive to their children, we also coded individual behaviors that the parents and children engaged in, as reflected by their talk, just as we did in the Specific Supports pilot study. In this study, we focused on the behaviors that were significantly related to parent math anxiety in the pilot study. We coded how many times the parent, and how many times the child, generated a new strategy for the pair to use to solve the problem, whether they named it out loud, or just began to use the strategy (e.g. "Count up five times"; counting on fingers). We also counted the number of times parents disagreed with their child. We divided disagreement into two types, when parents expressed disagreement and no other information (e.g., "No. 7 plus 6 is not 12"), and when they disagreed but provided an explanation (e.g., “No. You're subtracting, not adding”). We also tried to code parent confusion, but it was so infrequent that we were not able to include this in our analyses. Again, the reliability coder got reliable on a subset of 18 videos (20.2%). The unit of analysis was each individual item for this coding scheme, so reliability was calculated for each item. The coders were reliable with ICC (2, 1) = .87 for child strategies, ICC (2, 1) = .951 for parent strategies, ICC (2, 1) = .729 for total disagreements, and ICC (2, 1) = .765 for disagreements with explanations (Koo & Li, 2016).

Results

Manipulation Check

After completing the math task parents were asked to indicate the amount of performance pressure they felt in regard to supporting their child and helping him or to perform well on the task, on a scale of 1 to 7 (Beilock et al., 2004). Parents in the pressure condition ($M = 4.35$, $SD = 1.95$) reported feeling more pressure than those in the control condition ($M = 3.33$, $SD = 1.67$), and this difference was statistically significant $t(86) = -2.631$, $p = .010$. This suggests that the pressure manipulation was successful in inducing pressure in participants. A median split of parent math anxiety also revealed that higher math anxious parents felt more pressure than lower math anxious parents, but this effect was marginal rather than statistically significant, $t(86) = -1.889$, $p = .062$.

Descriptive Statistics

Variable Coding and Transformations.

87 of the 89 parents reported their highest level of education, and 86 reported their household income. In order to make the income and education variables more continuous, for income, each parent received a value equivalent to the median of the income bracket that they were in. For example, those earning between $35,000 and $49,999 received a value of $42,500. Those with a household income of over $90,000, the highest bracket, received a value of $90,000. For education, each parent received a value equivalent to the number of years of education completed. Those who completed high school were coded as 12, those who completed some college, 13, those who completed an associate's degree 14, those who completed a BA 16, and so on, with the highest value being those who completed a graduate degree who were coded as 18.

For all analyses, the pressure condition was coded as 1, and the control condition as -1. For gender, girls were coded as -1 and boys as 1. Parent and child math anxiety and family income were transformed into standardized z scores.

Demographics: Income and Education.

After this coding was complete, correlations were run on income and education. Income and education were correlated at $r = .634$, $p = .000$. Both income and education were also correlated with parent math anxiety. Parent math anxiety and education were correlated at $r = -.333$, $p = .002$, while parent math anxiety and income are correlated at $r = -.381$, $p =.000$. Child math anxiety was significantly correlated with parent education ($r = -.272$, $p = .010$), but not parent income (-.134, $p = .217$), but these correlations did not significant differ ($z = -.095$, $p = 0.342$).

Parent and Child Anxiety and Ability.

Parent math anxiety ranged from 1 to 4.52, with a mean of 2.26, and a standard deviation of .87. Child math anxiety ranged from 1.13 to 4.13 with a mean of 2.53 and a standard deviation of .71. Children's Woodcock Johnson W scores ranged from 417 to 515, with a mean of 468.52 and a standard deviation of 20.98. See Table 4 for these variables by condition.

Problems Solved Together.

We counted the number of problems that the dyad solved together as any problems that were coded according to the criteria described approve (excluding incomplete, skipped, or never discussed problems). The number of problems solved together by each dyad in the course of the 10 minutes allowed for the interaction ranged from 1 to 15, with a mean of 5.47, and a standard deviation of 3.07. Those in the pressure condition ($M = 6.34$, $SD = 3.37$) solved more problems together than those in the control condition ($M = 4.62$, $SD = 2.5$). An independent samples Welch's t test revealed this difference to be significant, $t(79.28) = -2.729$, $p = .008$. This is presumably because those in the pressure condition were instructed that their work would be graded. There not a statistically significant, correlation between the number of problems solved and parent math anxiety, $r = .169$, $p=.114$.

Table 4. Parent and Child Attitudes and Ability by Condition

		Minimum	Maximum	Mean	Std. Deviation
Control Condition	Parent Math Anxiety Average	1.04	4.52	2.31	0.84
	Child Math Anxiety Average Score	1.44	4.00	2.56	0.66
	Child WJ Applied Problems W Score	431.00	506.00	466.91	18.67
Pressure Condition	Parent Math Anxiety Average	1.00	4.48	2.20	0.91
	Child Math Anxiety Average Score	1.13	4.13	2.49	0.76
	Child WJ Applied Problems W Score	417.00	515.00	470.16	23.22

Results of Modified RTOP Coding Scheme

Modified RTOP Score.

We calculated the average score across all problems for each item for each family. For example, a parent may have averaged 2.5 for the item concerning patience across the 10 problems that they completed. Once we obtained each parent's average score for each of the 6 items on the modified RTOP, we standardized their scores (z-scores) for each item, and then averaged the six z-scores to create a composite standardized average. Parents scores on the modified RTOP ranged from -1.45 to 1.24 with a mean of 0 (because they are composites of z-scores) and a standard deviation of .69.

Modified RTOP Regressions.

For all regressions reported, we excluded from analysis one family who did not report the age of their child, and two families who did not report their income.

We performed a linear regression with the parents' standardized composite measure of instruction quality as an outcome measure and Condition, Parent Math Anxiety, the interaction between Condition and Parent Math Anxiety, Child Gender, Child Math Anxiety, Child Applied Problems W Score, Child Age, and Family Income as predictors (See Table 5 for full model betas and p values).

As reported above, parent income was highly correlated with parent education (though one parent did not report education and two did not report income) so including income in the model could also serve as something of a proxy for socio-economic status and education.

Table 5. Regression Model Descriptions for Modified RTOP Analysis

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-2.639	1.664		-1.586	0.117
	Condition	-0.189	0.067	-0.272	-2.827	0.006 *
	Parent Math Anxiety Z Score	-0.160	0.072	-0.230	-2.219	0.029 *
	Interaction Between Parent Math Anxiety Z Score and Condition	-0.020	0.068	-0.029	-0.296	0.768
	Child Math Anxiety Z Score	-0.131	0.072	-0.188	-1.833	0.071
	Child Applied Problems W Score	0.006	0.004	0.172	1.581	0.118
	Income Z Score	0.120	0.074	0.171	1.605	0.113
	Child Age in Months Z Score	0.112	0.071	0.160	1.560	0.123
	Child Gender	-0.035	0.067	-0.050	-0.515	0.608

a. Dependent Variable: Score on Modified RTOP

Using a linear regression, we found that Condition significantly predicted RTOP score, such that being in the pressure condition was associated with a lower RTOP score. Parent math anxiety also significantly predicted RTOP score, such that higher math anxious parents scored lower on the RTOP (See Figures 2 and 3). The child being older or scoring higher on the Woodcock Johnson Applied Problems was not associated with a higher RTOP score. Finally, there was a marginal effect of the child's math anxiety on the modified RTOP score such that dyads more math anxious children had lower RTOP scores. There was no significant interaction between condition and parent math anxiety in this model, nor was there a significant effect of child gender[1].

[1] Parent education was not included in this model as it is highly correlated with family income (r = .634, p = .000). Here I report the effect of inducing family education instead of parent income in the model predicting modified RTOP score. For this analysis, the two participants who reported their education but not income were included, and one participant who did not report education was excluded. All z-scores in the model were re-calculated to reflect these changes. In this analysis, condition (t = -3.236, p=.002, b= -.201, SE=0.062) and parent math anxiety (t = -2.315, p=.023, b= -.152, SE=0.066) remained significant predictors. Education itself was a significant predictor of RTOP score, with parents who had more years of education scoring higher on the RTOP (t = 2.949, p=.004, b= .206, SE=0.070).

Figure 2. Modified RTOP Score by Condition and Parent Math Anxiety

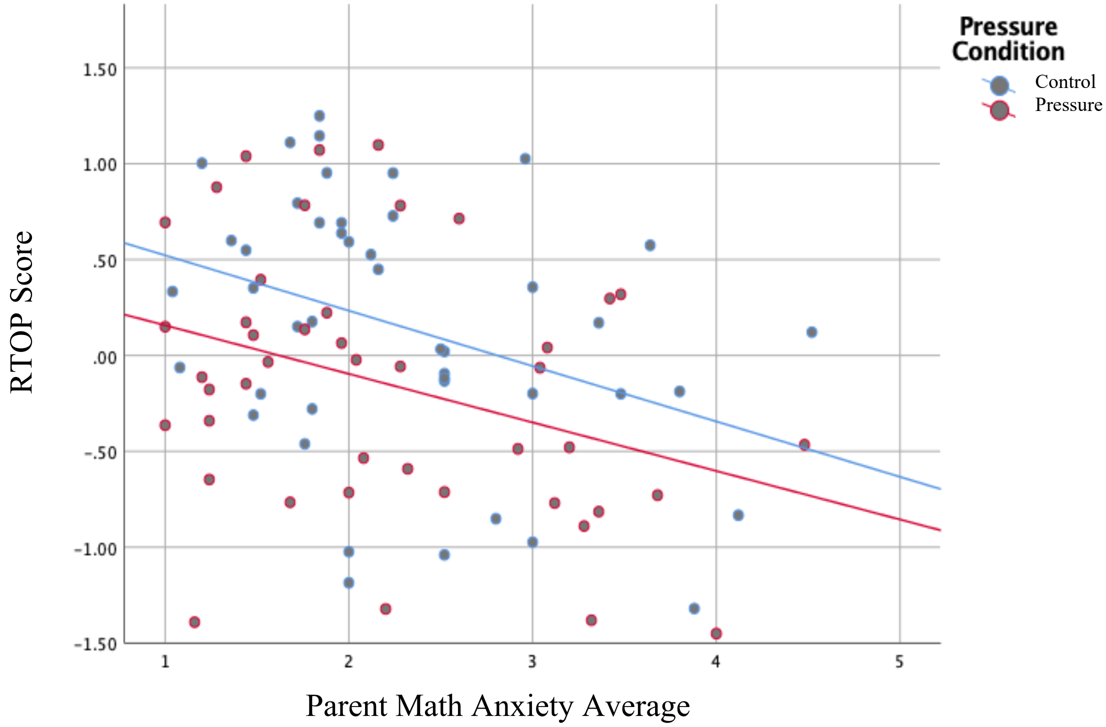
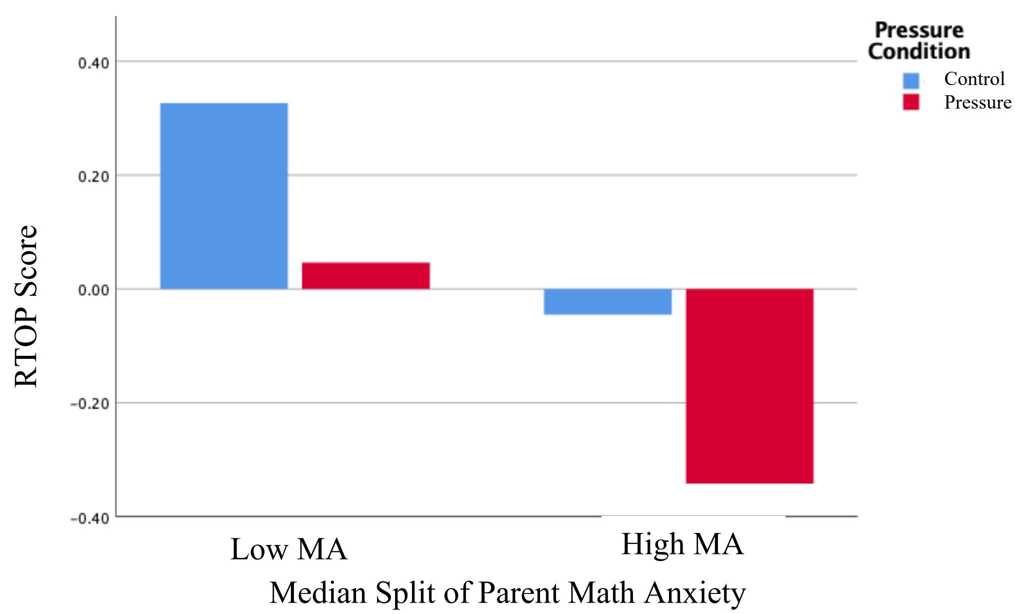


Figure 3. Modified RTOP Score by Condition and Median Split of Parent Math Anxiety



Individual Items.

Because the coders were not able to get reliable at the item level, and the modified RTOP was not designed to be used item by item, it is best not to interpret the predictive power of any one item. Rather this scale should be understood to offer an overall sense of teaching quality. Furthermore, the items that make up the RTOP were internally consistent, with a Chronbach's Alpha of .785.

Results of Specific Counts Scale

Strategies Descriptive Statistics.

The average number of strategies per problem suggested by the parent ranged from .25 to 3.5 (M = 1.43, SD = .69). The average strategies per problem suggested by the child ranged from 0 to 3.5 (M = .93, SD = .70). The total number of strategies suggested by the parent was negatively correlated with the number suggested by the child, r = -.349, p = .001. This implies that it was generally either the parent or the child who was taking charge of the conversation. The proportion of total strategies that the dyad came up with that were suggested by the parent ranged from .13 to 1.0 (M = .62, SD = .24).

Disagreements Descriptive Statistics.

We measured the number of times the parent disagreed with the child as a total number across the interaction. The total number of disagreements ranged from 0 to 13 (M = 4, SD = 2.9). The number of disagreements with explanations ranged from 0 to 7, with a mean of 1.84 and a standard deviation of 1.70. The number of disagreements without explanations ranged from 0 to 8 with a mean of 2.16 and a standard deviation of 2.11.

Strategies Regression.

For all regressions reported, we excluded form analysis one family who did not report the age of their child, and two families who did not report their income.

The first outcome variable of interest was the proportion of strategies suggested by the parent. This allows us to see how much of the cognitive load of problem solving was being performed by the parent rather than the child. Because our outcome variable was a proportion, we carried out a binomial logistic regression with family as a random effect. For this model, the children's w scores were centered by subtracting the overall mean from each child's w score, in order to rescale the data so that the model could converge (Howell, 2013).

The predictors were the same as those used for the analysis of the RTOP scale, Condition, Parent Math Anxiety, the interaction between Condition and Parent Math Anxiety, Child Gender, Child Math Anxiety, Child Applied Problems W Score, Child Age, and Family Income (See Table 6 for full model betas and p values).

There was a main effect of Condition, such that in the pressure condition parents suggested a larger proportion of the dyad's strategies. Parent math anxiety was not related to the proportion of strategies suggested. The child earning a higher w score was associated with the parent providing a smaller proportion of the dyad's strategies. There was not a significant effect of the interaction between condition and parent math anxiety, child math anxiety, child grade, or child gender on the proportion of strategies suggested by the parent[2].

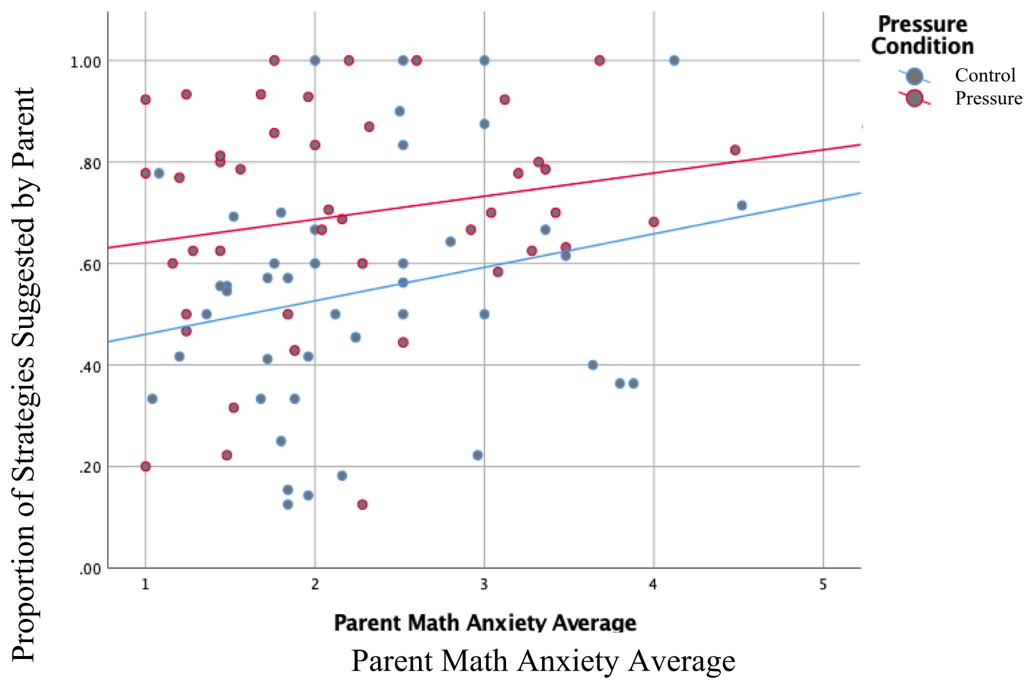
[2] Here I report the effect of inducing family education instead of parent income in the model predicting the proportion of strategies suggested by the parent. For this analysis, the two participants who reported their education but not income were included, and one participant who did not report education was excluded. All z-scores in the model were re-calculated to reflect these changes. In this analysis, condition (z = 3.267, p=.001, b= 0.37, SE=0.114) and child Applied Problems score (z = -2.361, p=.018, b= -0.015, SE=0.006) remained significant

Table 6. Regression Model Descriptions for Proportion of Strategies Analysis

Model		Unstand Coeff B	Std. Error	z	Sig.
2	(Constant)	0.630	0.113	5.575	2.47E-08
	Condition	0.331	0.11667	2.838	0.005 *
	Parent Math Anxiety Z Score	0.0941	0.123	0.765	0.444
	Child Math Anxiety Z Score	0.0134	0.124	0.108	0.914
	Child Applied Problems W Score	-0.015	0.006	-2.28	0.023 *
	Income Z Score	-0.198	0.131	-1.51	0.131
	Child Age in Months Z Score	0.071	0.124	0.569	0.569
	Child Gender	0.108	0.117	0.919	0.358
	Interaction Between Parent Math Anxiety Z Score and Condition	-0.038	0.115	-0.336	0.737

a. Dependent Variable: Proportion of Strategies Suggested by Parent

Figure 4. Proportion of Strategies Suggested by Parent by Condition and Parent Math Anxiety



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predictors). Education itself was not a significant predictor of the proportion of strategies suggest by the parent (z = 1.046,, p=.295, b= -0.14, SE=0.131).

Total Disagreements Regression.

For all regressions reported, we excluded form analysis one family who did not report the age of their child, and two families who did not report their income.

We looked at the overall number of disagreements that the parent had with the child. For the number of disagreements, we used a Poisson distribution to account for the fact that our outcome variable was count data, with family as a random effect. The same predictors were used as in the analysis of the strategies above, Condition, Parent Math Anxiety, the interaction between Condition and Parent Math Anxiety, Child Gender, Child Math Anxiety, Child Applied Problems W Score, Child Age and Family Income. We also added the log of the number of problems solved as a predictor, to account for the fact that the outcome variable was a total count rather than an average. For this model again, the overall mean of the sample's w scores was subtracted from each child's w score, in order to rescale the data so that the model could converge[3] (See Table 7 for full model betas and p values).

[3] Here I report the effect of inducing family education instead of parent income in the model predicting the number of total disagreements suggested by the parent. For this analysis, the two participants who reported their education but not income were included, and one participant who did not report education was excluded. All z-scores in the model were re-calculated to reflect these changes. The outcome variable was the number of total disagreements suggested by the parent. Child Applied Problems score (z = -3.024, p=.003, b= -0.013, SE=0.004) and the log of the number of problems completed (z = 3.138,, p=.0017, b= 0.50, SE=0.159) remained significant predictors, and parent math anxiety remained a marginal predictor (z = -1.595, p=.111, b= -0.136, SE=0.085). Education itself was not a significant predictor of the total number of disagreements suggest by the parent (z = -0.143, p=.886, b= -0.013, SE=0.088).

Table 7. Regression Model Descriptions for Number of Disagreements Analysis

Model		Unstandardized Coefficients			
		B	Std. Error	z	Sig.
3	(Constant)	0.498	0.277	1.795	0.073
	Condition	-0.033	0.079	-0.420	0.677
	Parent Math Anxiety Z Score	-0.149	0.087	-1.717	0.086
	Child Math Anxiety Z Score	-0.016957	0.083954	-0.202	0.840
	Child Applied Problems W Score	-0.012929	0.004411	-2.931	0.003 *
	Income Z Score	-0.017199	0.086155	-0.200	0.842
	Child Age in Months Z Score	0.031001	0.080567	0.385	0.700
	Child Gender	0.109373	0.076736	1.425	0.154
	Interaction Between Parent Math Anxiety Z Score and Condition	0.032136	0.081074	0.396	0.692
	Log of Problem Count	0.489318	0.162902	3.004	0.003 *

a. Dependent Variable: Total Disagreements Suggested by Parent

There was a marginal effect of parent math anxiety such that more math anxious parents offered fewer disagreements, and a negative effect of child math achievement such that parents disagreed less often with higher achieving children [4][5].

Overall Associations

Relation Between the Two Coding Schemes.

Modified RTOP Score was negatively correlated with the proportion of strategies suggested by parents (r = -.475, p = .000), such that parents who did more of the work generating strategies scored lower on the RTOP. The average number of times that the parent disagreed with

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[4] We also planned to look specifically at the number of disagreements the parent made that were accompanied by explanations. across the interaction. The number of disagreements with explanations that parents made over the course of the ten minutes ranged from 0 to 7, with a mean of 1.84 and a standard deviation of 1.70. A full quarter (22 out of 89) of the total parent participants never offered a disagreement with an explanation, and more than half (46 out of 89) offered 3 or fewer over the course of the entire 10 minutes. Therefore, caution should be made when drawing conclusions about this data. We report the results of the analysis here, for the sake of transparency: Again, we used a Poisson distribution to account for the fact that our outcome variable was count data. The same predictors were used again, including the log of the number of problems. There was a significant effect of parent math anxiety, such that higher math anxious parents disagreed with explanations less often (z = -2.49, p=.0128, b= -0.270, SE=0.109) and a significant effect of parent income such that higher income parents offered disagreements with explanations less often (z = -2.305, p=.0212, b= -0.252, SE=0.109). When education is included in the model and the outcome variable was the number of number disagreements suggested by the parent accompanied by an explanation, parent math anxiety (z = -1.794, p=.0729, b= -0.202, SE=0.112) becomes a marginal predictor, and no other variables are significant predictors.

[5] There was one parent who was an outlier in terms of disagreements, disagreeing with their child a total of 13 times, as compared to the overall mean the mean of 4 times and standard deviation of 2.9. When this dyad is removed from analysis the results do not change, with child w score still significantly predicting the number of disagreements (z = -3.02, p=.003, b= -0.013, SE=0.004, log of problem count also remaining a significant predictor (z = 3.52, p<.001, b= .556, SE=0.158, and parent math anxiety remaining a marginal predictor (z = -1.43, p=.152, b= -.120, SE=0.084.

the child per problem was correlated with neither RTOP score ($r = -.093$, $p = .385$) nor with the proportion of strategies suggested by parents ($r = .039$, $p =.713$).

Relation Between Coding Schemes and Task Accuracy in Pressure Condition.

We looked at the correlation between the various codes and task accuracy within the Pressure Condition, the condition where the dyads were not given the answers. Task accuracy was measured as the total number of correct problems divided by the total number of attempted problems. A problem was counted as attempted if the dyad wrote an answer on their problem sheet, whether or not the problem met the criteria to be coded (which was that the child did not solve the problem independently and the dyad completely finished discussing the problem). Task accuracy ranged from 50% to 100%, with a mean of 92.84% and a standard deviation of 11.6%. Task accuracy was correlated with modified RTOP score, $r(44) = .521$, $p < .001$. This makes sense as one of the items that makes up the modified RTOP score is the parents' grasp of the subject matter, an item which will receive a lower score if the dyad gets the problem wrong. However, even when the item concerning the parent's comprehension of the subject matter was removed from the modified RTOP scale, task accuracy and modified RTOP score remained correlated at $r(44) = .382$, $p = .011$. The percent of strategies suggested by the parent was not correlated with task accuracy, $r(44) = -.052$, $p = .738$, nor was the average number of disagreements per problem, $r(44) = -.123$, $p = .452$.

Power Analysis.

Using G*Power, I conducted a power analysis of a linear regression using 8 predictors, as were used in this study. With a medium effect size of $f^2 = .15$ (Cohen, 1988), this study required a sample size of 109 to detect a significant R^2. Therefore, this study, which had a sample of 89 participants, was underpowered to detect effects.

Discussion

Parent Math Anxiety

High math anxious parents were found to score lower on the modified RTOP, which measures their respect for their children's prior knowledge, ability to offer opportunities for exploration and promote conceptual understanding, their own understanding of the problem, and the extent to which they encourage critical thinking, as well as their level of patience, as compared to low math anxious parents. This seems to suggest that high math anxious parents are using fewer teaching techniques that have been found to be effective compared to low math anxious parents (Sawada et al., 2002; Roehrig, Kruse & Kern, 2006). This main effect did not interact with condition, suggesting that high math anxious parents do not use the same teaching techniques as low math anxious parents regardless of whether the situation is relaxed or high pressure. However, for all parents, teaching quality was lower in the high-pressure situation.

On the more detailed Specific Supports coding scheme, we did not find an effect of math anxiety on the proportion of strategies suggested by the parent. This stands in contrast to our pilot study with older children, which indicated that high math anxious parents suggested a smaller proportion of the dyad's strategies. One possibility is that this represents a developmental shift, wherein high math anxious parents are more likely than low math anxious parents to cede control, but only when their children are older. For older children, the math content is more difficult, and parents might view their children as more capable in math than they themselves are. If this is the case, it could be that high math anxious parents avoid math during home math interactions but only after their children are old enough for that to be feasible.

There was a marginal effect by which higher math anxious parents were less likely to disagree with their children, as we found in the study of older children. This may indicate that with younger, as with older children, higher math anxious parents do not feel as confident offering an opinion contrary to their child. This is a reliable effect in the study of older children, but only marginal here, perhaps indicating that this tendency for higher math anxious parents to defer to their children increases as the children grow.

Overall, these findings indicate that high math anxious parents may not be optimally responsive to their young children, not offering them high quality instruction as reflected in their modified RTOP scores. And in combination with our pilot study, this data hints that though parents of younger children may not be as hands off as they are with older children, they may still perhaps feel reluctant to disagree with their child. This possibility should be further investigated. Over the course of children's education, these interactions may lead to lower amounts of math learning in the home, explaining the observed math achievement gap between the children of high and low anxious parents (Berkowitz et al., 2015; Schaeffer et al., 2018; Soni & Kumari, 2015).

Condition

Parents in the pressure condition solved more problems than those in the control condition. Additionally, on the Modified RTOP scale those in the high-pressure condition scored lower than those in the control condition. This makes intuitive sense, as parents who are feeling pressure and struggling to finish as many problems as possible with their child are not able to offer the highest quality instruction. Doing well on all of the items that make up the scale may be more difficult when there is time pressure, and when parents' cognitive resources are strained by performance pressure (Belock & Carr, 2005; Ashcraft & Krause, 2007). These parents may have had a hard time doing the type of constructionist teaching that the modified RTOP rewards, which includes allowing the child to explore the problem and promoting a larger conceptual understanding of the material. This may be the reason that Modified RTOP Score is negatively correlated with the proportion of strategies suggested by the parent on the Specific Counts Scale, as parents who are intrusive and take over the cognitive load of problem solving are not allowing their children to wrestle with the content themselves.

Indeed, a more specific look at the interactions using the Specific Counts Scale, reveals that parents who were in the pressure condition generated a larger proportion of the strategies used to solve the problem than those who were not under pressure. Again, this could be because the parents in the pressure condition were motivated to move quickly through the interaction and ensure accuracy, both of which are made difficult when a child is driving the interaction by suggesting strategies. This could be detrimental to the child who is not given the opportunity to think through the material by themselves (Stigler & Hiebert, 1999). High pressure interactions may therefore not be conducive to learning in the home.

We did not find condition differences in the number of times that parents disagreed with their child. This could be because these children are younger, and parents feel more confident correcting them whether under pressure or not. This supposition is supported by the lack of expressions of confusion by parents in this sample.

Child Factors

Of course, in any interaction the parent is not the only relevant factor. In this study we found that individual differences in the children also played a part in determining what the interaction looked like. On the Specific Supports coding scheme we found a main effect of child math ability, such that parents suggested a smaller proportion of the strategies when their child had more math ability. With regard to disagreements, child math achievement was important again as parents with higher achieving children disagreed with their child less often. These effects could be either due to parents trusting more in the math ability of their child when the child is higher achieving, or due to children whose parents trust more in their math ability learning more math throughout their lives, or both. Future studies could better untangle the causal direction of this relation.

Limitations

This study had several limitations which should be kept in mind. This study was underpowered and coding the rest of the videos in the full sample would help to see if these effects hold or change with increased power. Perhaps the most important limitation is that the coders could see and hear that some families had the answers to the math problems, while others did not. Though the coders did not know why this was the case, they knew which families had the answers and we must consider the possibility that this may have somehow biased the relation between their codes and condition effects. Future studies should enact a pressure manipulation which does not contain a component that can be seen on camera or on a participant's answer sheet and that is less likely to be discussed by the parent and child during the course of solving the math problems. Another limitation concerns the coding scales themselves. These coding schemes should be further validated through other studies before they can be widely adopted.

Future studies should also spend longer on reliability, so that item by item comparisons can be made on the modified RTOP. Finally, it is not clear how similar these math intersections in the lab are to those that take place in the home during homework help and other activities. The external validity of this study could be improved by expansions and replications directly in the home.

Future Directions

The results of the current study present opportunities to develop effective interventions for math anxious parents. For example, advising parents to let their children explore the problem independently before jumping in to teach may improve the quality of the math interactions that high math anxious parents have with their children. Another approach would be to develop clear and high-quality explanations that help parents support children's math learnings. A clear explanation of the conceptual underpinnings of a math problem may help high math anxious parents to understand the problem better themselves, thus improving the quality of the instruction that they provide to their children.

Another avenue of future research could involve efforts to lessen parent anxiety or pressure during math interactions, to see if this leads to improved quality of math help. It would be very informative to measure parents' anxiety levels during math interactions and see if interventions designed to reduce anxiety improve the quality of their math interactions with their children. This approach could be compared to those described above, which involve supporting the quality of the parent-child math interactions. Measuring parents' anxiety, either via surveys or physiologically, during routine parent/child math interactions would also help us to find if high math anxious parents feel more feel pressure during these interactions.

Future research should also assess whether there are similar instructional differences evident between high and low math anxious teachers, or teachers who are under pressure and those who are not. It is possible that classroom teachers show similar changes in instruction when they themselves feel math anxious (Hembree, 1990; Beilock et al.., 2010). Because the modified RTOP scale that was used in this study was based on a teacher rating scale, the same scale could be used to rate teachers, perhaps with slight modifications to make it more similar to the original validated RTOP.

Finally, future studies should explore the relation between the quality of math interactions, as measured by these scales, and child math achievement outcomes. A direct examination of parent performance on this scale and later student math outcomes would reveal the extent to which these instructional differences matter in terms of improving student performance when it comes to math interactions. It will therefore be informative to investigate whether these same scales reveal difference between more and less scaffolded math conversations, or between homework and more engaging math activities in the future.

STUDY 3: What types of interventions are effective in breaking the relation between parent math anxiety and child math performance?

General Background

In Study 3, I investigate how socio-emotional differences in parents influence students' math performance. We conducted a randomized control trial to test whether a math app intervention condition could raise children's math achievement compared to an active reading app control condition. We also examined whether, as in a higher SES (socio-economic status) sample, the benefit of the math app was specific to families in which parents were high in math anxiety.

The current study set out to examine whether using an educational math app was associated with math gains in children from low income families during first grade. Income-related math achievement gaps persist within the U.S. and this gap has widened in recent years (Reardon, 2011; Larson, Russ, Nelson, Olson, & Halfon, 2015; Eason, in prep). Children from lower-income, lower-SES families tend to underperform in math compared to their peers from higher-income, higher-SES families (Jordan, Kaplan, Ramineni & Locuniak, 2009), and typically have less access to resources that support educational attainment. Lower SES students underperform throughout schooling, with an SES achievement gap present already at kindergarten and widening into middle school (Elliott & Bachman, 2018; Sirin, 2005). For example, Jordan et al. (2009), found that lower SES children made slower progress in learning math between 1st and 3rd grade than higher SES children, and this difference was mediated by the students' kindergarten number abilities. Home and school math input can make a difference, and children who have learning tools like books and CDs in their homes, and whose parents are more involved with their school have better math outcomes, regardless of SES (Galindo & Sheldon, 2012; Galindo & Sonnenschein, 2015).

Lower SES children therefore potentially have the most to gain from math interventions in the home. Furthermore, by examining whether interventions that have been shown to be effective in predominantly higher-income populations are also effective in a sample which differs demographically, we can learn more about both the intervention itself, and how best to support a wider array of families (Medin, Ojalehto, Marin, and Bang, 2017). For example, Berkowitz et al. (under review) found that higher math anxious parents used less number talk with their pre-school aged children, but only in a higher SES sample. Lower SES parents did not show this parent math anxiety/number talk relation. Learning more about the factors relevant to each family's context will help us to understand the mechanisms by which parent attitudes impact children's learning.

The current study is a replication and expansion of previous research which showed a math achievement gap between children with high and low math anxious parents (Berkowitz et al., 2015), to see if the same achievement gap exists and can be closed in a lower income sample. The achievement gap between the children of high and low math anxious parents emerged at the end of first grade. At the beginning of the school year children did not differ in math performance based on parent math anxiety, whereas by the end of the school year those with higher math anxious parents underperform as compared to those with low math anxious parents (Berkowitz et al., 2015). It could be that this achievement gap opened up over the course of the school year because high math anxious parents were helping their children with homework throughout the school year. These homework help interactions may be high pressure, especially for math anxious parents (Maloney et al., 2015). During these interactions, high math anxious parents may be providing lower quality instruction, as I discuss in Study 2. The intervention study by Berkowitz et al. (2015), speaks to the potential of family math interventions to reduce the achievement gap associated with parent math anxiety. This study also found that an educational application called Bedtime Learning Together (BLT), can close the achievement gap between the children of high and low math anxious parents.

In the Berkowitz et al. (2015) study, the BLT app was given to families of first grade children who differed in socioeconomic status but who were mainly from middle to high income groups, with 69.4% of children coming from homes with household incomes of over $50,000. Each day the app presents a new passage about a topic of interest to children, like candy or castles. Families received either a math version of the app, which followed each passage with math questions at different difficulty levels, or a reading version of the app, which followed the passages with questions about reading comprehension. For those randomly assigned to the reading condition, an achievement gap between the children of low and high math anxious parents opened up over the course of first grade, with the children of high math anxious parents underperforming as compared to their peers with lower math anxious parents. For those in the math condition, no such achievement gap emerged.

This difference persisted over multiple years in a follow-up longitudinal study (Schaeffer et al., 2018). The effects of the app were found to be partially mediated by parents' expectations and values of their children, such that math anxious parents in the math app group valued math more for their children and had higher expectations of their child's math ability than similarly math anxious parents in the reading control group. Perhaps having a low-pressure way to do math with children changed high math anxious parents' attitudes about math and encouraged parents to let their child take the lead during math interactions in the home, in the ways characteristic of lower math anxious parents (see study 2).

Current Study

In the first year of our large-scale study, we administered the Bedtime Learning Together app to 449 first grade children from low-income families in the Chicagoland area. We also administered surveys to the children's parents to assess their attitudes and tested the children's math and reading abilities and attitudes. We aimed to assess whether the results of our initial study with a largely middle-income sample, would replicate in a lower income sample. This large replication will give us a great deal of information about whether this form of intervention works with low-income families and will allow us to assess how family math attitudes relate to children's math achievement in this important sample.

We began this two-year study in the Fall of 2018 and tested approximately half of our sample during the 2018-2019 school year. The remaining sample is being tested during the 2019-2020 academic year. The overarching goals of this study are to provide information about how teachers and parents math attitudes relate to children's math attitudes and math achievement in a large sample and test out the effectiveness of math app intervention.

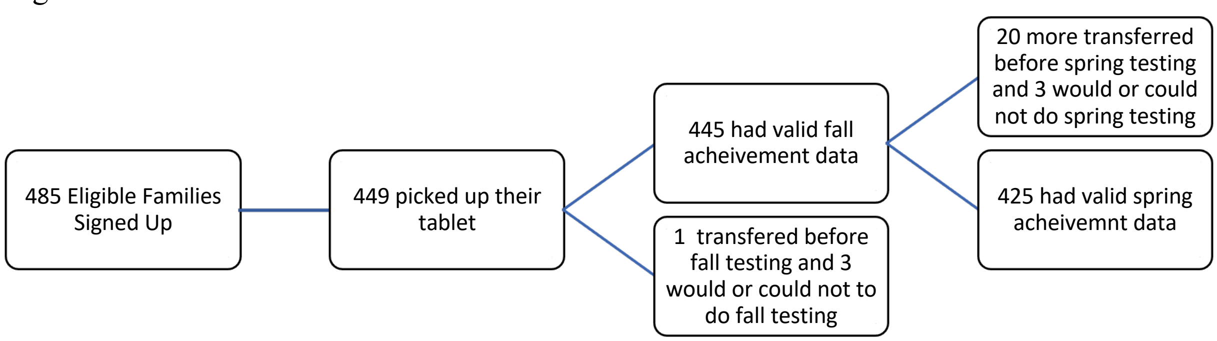
Methods

Participants

All schools recruited for this study provide free and reduced lunch to at least 50% of their pupils (range: 52.2% - 91.2%). When children were twins or were otherwise being raised by the same primary caregiver (e.g. cousins being raised by a grandmother), one child was randomly selected to be included in the analysis. Students were assigned to a condition randomly within classrooms.

We recruited 485 first grade families from 24 schools throughout the Chicagoland area. In the below analyses, we exclude those families who never picked up their tablets (See Figure 5). Reasons for having no valid fall or spring achievement data were transferring (21), and not being able or willing to complete the task (3). Of the 449 included children, 369 primary caregivers identified their child's race or ethnicity as African American/Black, 12 identified as Hispanic, 10 as Hispanic and Latino, 2 as Latino, 3 as Asian/Asian-American, 2 as Caucasian/White, 1 as Native American, 8 as other races, 7 chose not to answer the question, and the rest identified as biracial or multiracial. Of the 449 included children, 226 (107 boys, 119 girls) were in the reading condition, and 223 (112 boys, 111 girls) were in the math condition.

Figure 5. Reasons for Attrition



Measures

Parent Surveys.

Parents were given a survey to complete prior to receiving their tablet. The survey included the short Mathematics Anxiety Rating Scale (sMARS Alexander & Martray, 1989), which consists of 25-items, to measure parent math anxiety. To measure parent's beliefs about their efficacy in teaching we also administered the Mathematics Teaching Efficacy Beliefs Instrument, personal mathematics teaching efficacy subscale (MTEBI, Enochs, Smith, &

Huinker, 2000; Yates, 2014). We made minor modifications to this scale to ensure that it applied to the ways that parents, rather than teachers, might provide math support to their children. Parents also completed measures of spatial (Lyons et al., 2018) and reading anxiety, theories of intelligence, expectations about math and valuing of math for their child (Schaeffer et al., 2018), math homework help confidence (Maloney et al., 2015), and math and reading/literacy activities they engage in at home (Berkowitz, 2018). We also asked about parents' income and education. Parents indicated which of 6 income categories they fell into (See Table 8 for all categories).

Teacher surveys.

Students' teachers were also surveyed halfway through the school year. The teachers answered questionnaires about various attitudes and beliefs, including their math anxiety (sMARS Alexander & Martray, 1989), test anxiety, teaching math self-efficacy and theories of intelligence.

Child achievement measures.

Children were tested in their elementary schools. On the first day of testing children completed a battery of achievement measures measuring their math and reading competencies. This consisted of the Woodcock Johnson Applied Problems (Woodcock, McGrew, & Mather, 2001), Woodcock Johnson Math Fluency, Woodcock Johnson Letter-Word ID, Woodcock Johnson Picture-Vocabulary, a measure of children's ability to put numbers on a number line Number Line (0-100 and 0-1000), and a Letter Span and visuo-spatial working memory task to test children's working memory.

Child attitude/emotion measures

On the second day of testing children completed a battery of emotion measures, testing their feelings and attitudes about reading and math. These consisted of measures of child math anxiety (Ramirez et al., 2013), spatial anxiety, and reading anxiety, theories of intelligence, school subject preferences, math self-efficacy (adapted from Midgley et al., 1996), math and reading expectations and values (Schaeffer et al., 2018), and a drawing task designed to measure math stereotypes (Steele, 2003).

Results

Data Transformations

For all income analyses, the median of the range of incomes for that bracket was used. For example, if a parent’s income between $0 and $15,000, the value of $7,500 was used for that parent. For those in the highest income bracket, $100,000 and above, the value of $107,500 was used. In this sample, a plurality of parents earned less than $15,000 a year (See Table 8).

Again, as in Study 2, education was similarly coded for all analyses. Each parent’s education was coded to reflect the number of years of education completed. Those who did not complete high school received a code of 10, those who completed high school received a code of 12, those who completed some college, 13, those who completed an associate degree 14, and so on, with those who completed a graduate degree coded as 18.

For all analyses, the pressure condition was coded as 1, and the control condition as -1. For gender, girls were coded as -1 and boys as 1. Parent math anxiety was transformed into standardized z scores.

Descriptive Statistics

There was not a significant difference in our continuous measure of income (the median of the bracket) between the math (M = 31,976.74, SD = 29103,42) and reading (M = 29,107.98, SD = 2,8241.96) conditions, t(426) = -1.035, p = .301. In this sample overall, income was related to many other variables of interest, including children's achievement and parent math anxiety (See Table 10). Higher income parents reported experiencing less math anxiety. The children of higher income parents also scored higher on the Applied Problems in both the fall and spring. Higher income families also used the app more often. Furthermore, parents' feelings of efficacy in teaching their child math was positively correlated with income and app usage, and negatively correlated with parent math anxiety. In terms of primary care giver education, most participants were high school graduates (Table 9). Our continuous transformations of income and education were significantly correlated at r(422) = .599, p = .000 (See Table 10).

Table 8. Income Frequency Distributions

Household Income	**Number of Participants**
Less than 15,000	184
15,000 to 34,999	106
35,000 to 49,999	57
50,000 to 74,999	37
75000 to 99,999	21
100,000 or more	23

Table 9. Primary Caregiver Education Frequency Distributions

Primary Care Giver Education	**Number of Participants**
No High School Diploma	35
Completed HS or GED	126
At Least 1 Year College	108
Associate's Degree	63
Bachelor's Degree	42
Some Graduate Training (not completed)	25
Graduate Degree	38

Table 10. Performance and Attitude Correlations

		Income	Fall Applied Problems W Score	Spring Applied Problems W Score	Parent Math Anxiety	Average App Usage	Parent Teaching Efficacy
Fall Applied Problems W Score	Pearson Correlation	.165**					
	Sig. (2-tailed)	0.001					
	N	425					
Spring Applied Problems W Score	Pearson Correlation	.199**	.678**				
	Sig. (2-tailed)	0.000	0.000				
	N	406	425				
Parent Math Anxiety	Pearson Correlation	-.222**	-0.081	-0.091			
	Sig. (2-tailed)	0.000	0.087	0.060			
	N	427	444	424			
Average App Usage	Pearson Correlation	.236**	.159**	.235**	-0.029		
	Sig. (2-tailed)	0.000	0.001	0.000	0.535		
	N	428	445	425	448		
Parent Teaching Efficacy	Pearson Correlation	.175**	0.077	.119*	-.331**	.104*	
	Sig. (2-tailed)	0.000	0.111	0.015	0.000	0.029	
	N	420	435	416	439	439	
Parent Education	Pearson Correlation	.559**	.170**	.216**	-.207**	.215**	.280**
	Sig. (2-tailed)	0.000	0.000	0.000	0.000	0.000	0.000
	N	424	434	414	436	437	415
**. Correlation is significant at the 0.01 level (2-tailed).							
*. Correlation is significant at the 0.05 level (2-tailed).							

Gender and Math Performance.

We do not expect gender differences in math performance at this age (Herts & Levine, 2020). Indeed we did not find in gender differences in math performance in this sample, with girls (M = 447.58 SD = 14.61) showing Spring Applied Problems scores similar to that of boys (M = 449.25, SD = 17.11), t(423) = -1.083, p = 279..

App Usage.

Each families' amount of app usage was operationalized as the number of days per week on average that any member of the family (not a guest) used the app between the day after they received the app and the day that the child was spring tested. We started counting the day after the tablet was received because we used the app with each family on the day that they received it. Usage was low overall compared to our previous higher income sample (see Figure 6). Those in the math condition (M = .55, SD = .76) used the app more often than those in the reading condition (M = .50, S = .81), though usage did not differ significantly between conditions, t(447) = .427, p = .472. This was less usage than was typical of the higher income families in the Berkowitz et al. study (2015), where those in the math group were reported to use the app an average of 1.19 times per week, and those in the reading group an average of 1.61 times per week[1] (See Figure 7).

[1] The Bedtime Math version of the app used in the Berkowitz et al. (2015) study had a box to check off if the target child was using the app a box for a sibling to check off, and a box for a guest to check off. There were no boxes for parents or other household members. Usage was recorded only when the target child was checked. The version of the app used in this study had boxes to check for everybody in the household and another box for a guest. Usage was recorded whenever anybody except a guest used the app.

Figure 6. Usage Frequency by Condition

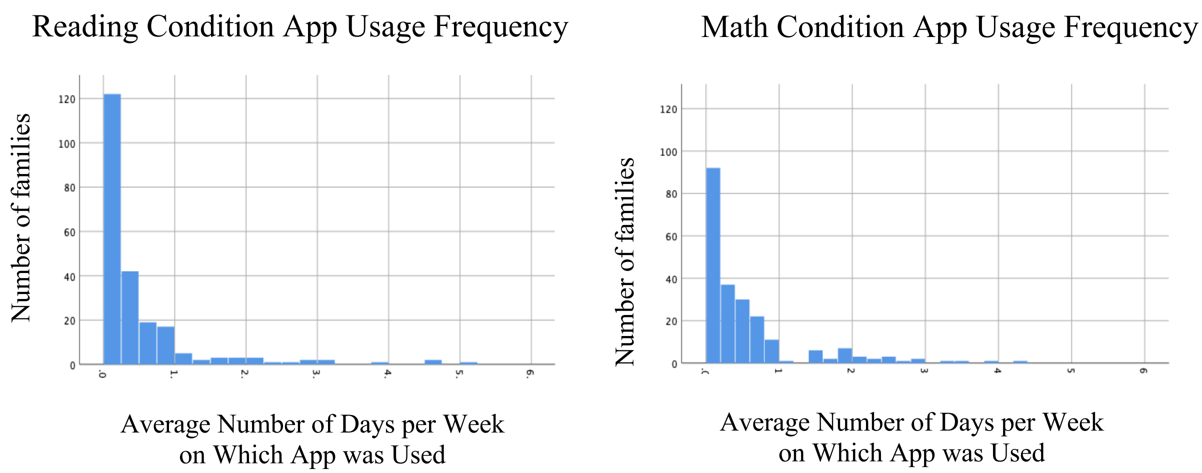
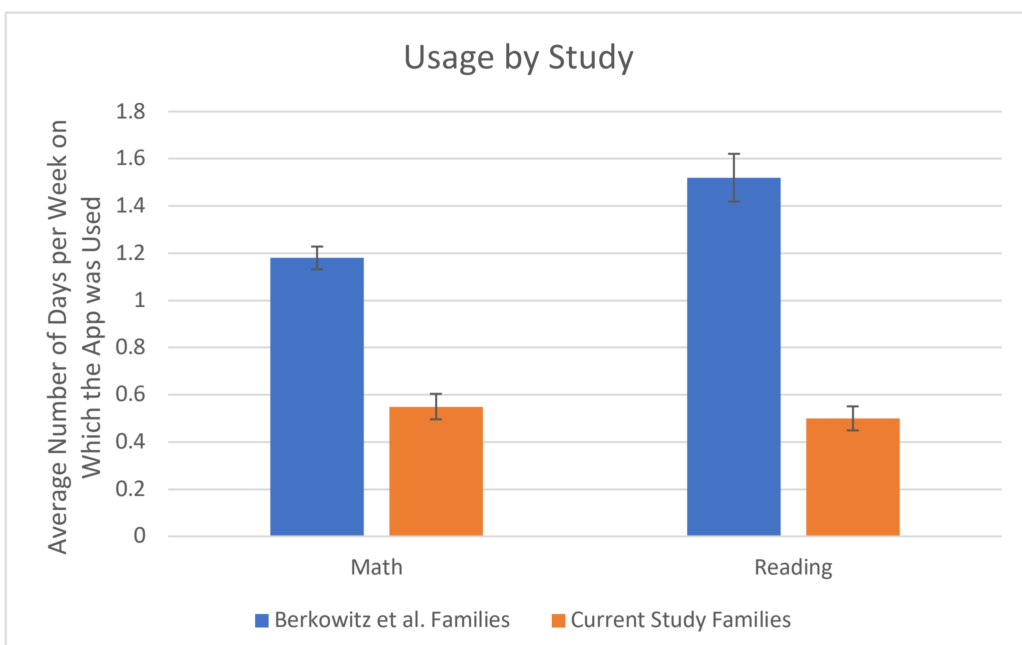


Figure 7. Usage in Current Study Compared to Previous Study

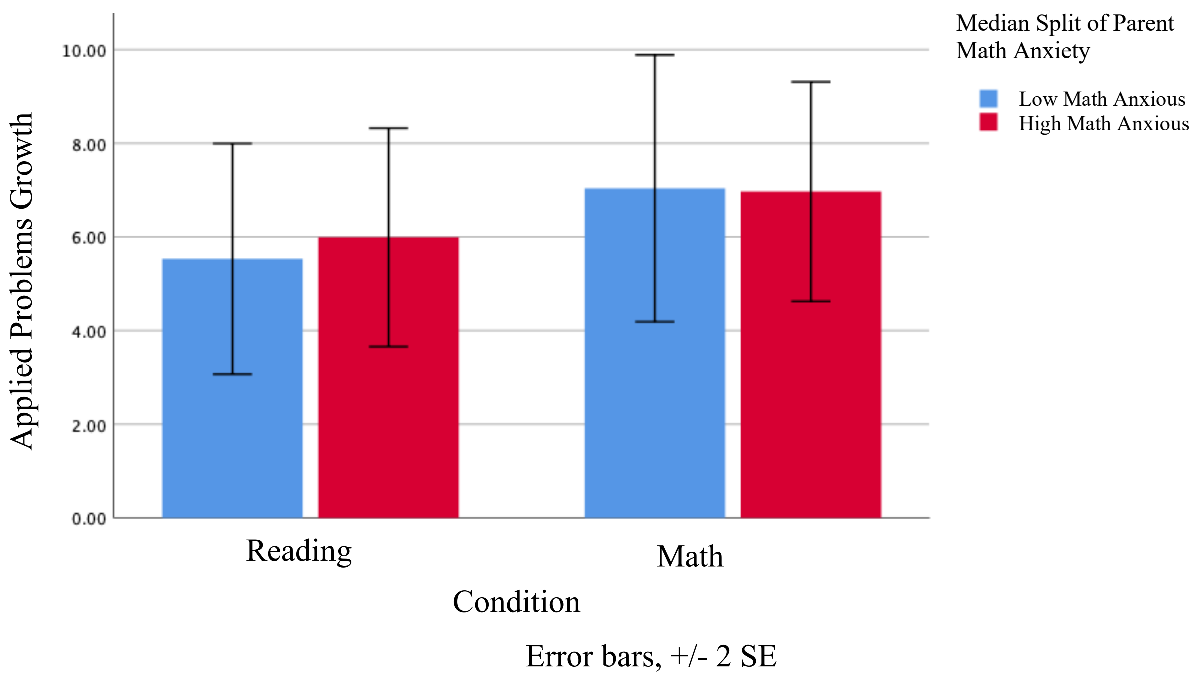


Error bars, +/- 1 SE

Math Growth.

Math Growth was operationalized as the change in Applied Problems W score from Fall to Spring. There was a lot of variability in math growth. The mean W score growth for participants in the math condition was 7.06 (SD = 13.29), while the mean growth for those in the reading condition was 5.76 (SD = 12.54). There was not a significant difference in growth between the two conditions, t(423) = -1.038, p = .300.

Figure 8. Math Growth by Condition and Parent Math Anxiety



Linear Models

For the following analyses, HLM 7 was used, with children nested within classrooms. Participants were excluded when data was missing. By allowing the slopes of every Level 1 variable to vary randomly, we discovered that only children's fall Applied Problems scores showed a strong reliability estimate (0.484 in the ITT analysis below) and significant random variation (as shown in the models below). We also believed theoretically that the relation between children's fall and spring Applied Problems scores could vary by classroom, with some teachers and schools having a bigger impact on this relation than others. Therefore, we allowed children's fall Applied Problems Scores to randomly vary, while keeping the other slopes fixed. Children's fall Applied Problems Scores were z scored, as were other predictors of interest including income, parent math anxiety, and parent teaching efficacy, in order to make the intercepts more interpretable and to help the models converge.

Intent to Treat Analysis.

Children were nested within classrooms (teachers) for this HLM analysis. The outcome variable was score on the Applied Problems subtest of the Woodcock Johnson test in the spring. Predictors were Applied Problems score in the fall, condition, and the z score of parent income. The only significant predictors were classroom, and Applied Problems fall score. Family income[2] was a marginal predictor There was also a significant random effect of classroom and Fall Applied Problems score, such that the relation between fall and spring Applied Problems

[2] Income and parent education are highly correlated, as reported above. If parent education is included in the intent to treat analysis instead of income, education is a significant predictor at t = 2.10, p=.037, b= -1.11, SE=0.53, and the significance of the other terms does not change.

score varied by classroom, and classroom itself was a predictor of spring performance even controlling for the other variables.

Table 11. Intent to Treat Analysis

Final estimation of fixed effects

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1 (Classroom Effect), β_0					
INTRCPT2, γ_{00}	448.141532	0.752416	595.603	41	<0.001
For Condition slope, β_1					
INTRCPT2, γ_{10}	0.541141	0.453397	1.194	320	0.234
For Income Z Score slope, β_2					
INTRCPT2, γ_{20}	0.990308	0.583993	1.696	320	0.091
For Fall Applied Problems slope, β_3					
INTRCPT2, γ_{30}	9.710186	0.855881	11.345	41	<0.001

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1 (Classroom Effect), u_0	3.35191	11.23529	41	67.09066	0.006
For Fall Applied Problems slope, u_3	3.98768	15.90156	41	81.09719	<0.001
level-1, r	10.43339	108.85569			

The outcome variable is Spring Applied Problems W Score.

Instrumental Variable Analysis.

This analysis was performed in two stages in HLM, nesting children within teachers. First, usage was put in as an outcome variable, with everybody in the reading condition receiving a usage value of 0. The predictors were condition, teacher, income (z scored), and fall Applied

Problem scores. Next, the fitted values from that model were used as a predictor of spring Applied Problems score. This let us know if the dosage of the treatment determined score on the spring Applied Problems, controlling for other variables of interest. As shown in Model 2, the dosage did not have a significant effect in this model. Again, we found that Fall Applied Problems score was a significant predictor of Spring Applied Problems score. There were also significant random effects of classroom and Fall Applied Problems score, such that the relation between fall and spring Applied Problems score varied by classroom, and classroom itself was a predictor of spring performance even controlling for the other variables in the model.

Table 12. Instrumental Variable Analysis

Final estimation of fixed effects

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1 (Classroom Effect), β_0					
INTRCPT2, γ_{00}	447.573476	0.949412	471.422	41	<0.001
For Income Z Score slope, β_1					
INTRCPT2, γ_{10}	0.790198	0.587275	1.346	320	0.179
For Fall Applied Problems Z Score slope, β_2					
INTRCPT2, γ_{20}	9.571778	0.825454	11.596	41	<0.001
For Fitted Value From Previous Model slope, β_3					
INTRCPT2, γ_{30}	2.096144	1.660247	1.263	320	0.208

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1 (Classroom Effect), u_0	3.35847	11.27929	41	66.87287	0.007
For Fall Applied Problems Z Score slope, u_2	3.9448	15.56145	41	79.68008	<0.001
level-1, *r*	10.43478	108.8847			

The outcome variable is Spring Applied Problems W Score.

Parent Math Attitudes Analysis.

For Model 3, the analysis was performed again, with spring Applied Problems again as the outcome variable. This time the predictors included the z score of parent math anxiety, and the interaction between condition and the z score of parent teaching self-efficacy and the z score of parent math anxiety. The only significant predictor was Applied Problems fall score, while z score of income was a marginal predictor. [3] There was also a significant random effect of classroom and fall Applied Problems score, such that the relation between fall and spring Applied Problems score varied by classroom, and classroom itself was a predictor of spring performance even controlling for the other variables.

Table 13. Parent Attitudes Analysis (continued on next page)

Final estimation of fixed effects
(with robust standard errors)

Fixed Effect	Coefficient	Standard error	*t*-ratio	Approx. *d.f.*	*p*-value
For INTRCPT1 (Classroom Effect), β_0					
INTRCPT2, γ_{00}	448.152797	0.755246	593.386	41	<0.001
For Condition slope, β_1					
INTRCPT2, γ_{10}	0.558205	0.473187	1.18	310	0.239
For Income Z Score slope, β_2					
INTRCPT2, γ_{20}	0.890571	0.622523	1.431	310	0.154
For Teaching Efficacy slope, β_3					
INTRCPT2, γ_{30}	0.597092	0.544546	1.096	310	0.274
For Parent Math Anxiety Z Score, β_4					
INTRCPT2, γ_{40}	-0.099373	0.420079	-0.237	310	0.813
For Parent MA x Condition Interaction slope, β_5					
INTRCPT2, γ_{50}	-0.677151	0.450234	-1.504	310	0.134
For Fall Applied Problems Z Score slope, β_6					
INTRCPT2, γ_{60}	9.709752	0.859424	11.298	41	<0.001

[3] If parent education is included in the Parent Attitude Analysis instead of income, education is a marginally significant predictor at $t = 1.602$, p=.110, b= .966, SE=0.60, and the significance of the other terms does not change.

Final estimation of variance components

Random Effect	Standard Deviation	Variance Component	*d.f.*	χ^2	*p*-value
INTRCPT1 (Classroom effect), u_0	3.3805	11.42777	41	66.56196	0.007
For Fall Applied Problems Z Score slope, u_6	4.01451	16.11628	41	79.34984	<0.001
level-1, *r*	10.4477	109.15451			

The outcome variable is Spring Applied Problems W Score.

Power Analysis.

Using G*Power, I conducted a power analysis of the Intent to Treat Analysis with three level 1 predictors (Condition, Income, and Fall Applied Problems score). Assuming a medium effect size of $f^2 = .15$ (Cohen, 1988), this study required a sample size of 77 classrooms to detect a significant R^2, and only 42 classrooms were included in the current analysis. This analysis was underpowered, because only half of the data from what will eventually be a two-year study were available.

Discussion

Whereas the original Berkowitz et al. (2015) study found that using the math app reduced the achievement gap between the children of high and low math anxious parents, the first year of this study did not find the same effect. With only half of the eventual sample for this study it is premature to draw firm conclusions about these results (we hope to collect the rest of the data this year, though the current Covid-19 pandemic may preclude us from doing so). It is possible that with the full sample we will find effects similar to those found in Berkowitz et al. (2015). Furthermore, although we cannot draw conclusions from null effects of the app, we did not find evidence consistent with this intervention being effective in this study. Below we consider some of the many possible reasons that the results of this study may differ from those obtained in the original BLT study.

The Impact of Family Income

Household income was correlated with child math achievement, years of parent education, app usage, and many other variables of interest. Therefore, we should consider the how household income may relate to the results of this study, and to interventions more broadly. Interventions are not one size fits all, and lower income populations may require different interventions better suited to their needs.

It is important to note that lower income parents report thinking that it is important to help their children with schoolwork (Drummond & Stipek, 2004). However, lower income parents may face different limitations than higher income parents who have more financial security (for example lower income parents may be working longer hours or experiencing more stress than higher income parents) (Whillans, Dunn, Smeets, Bekkers & Norton, 2017). For example, a longitudinal study of American children found that those from lower SES backgrounds used books and computers less at home than those from higher SES backgrounds (Larson, Russ, Nelson, Olson & Halfon, 2015). Furthermore, a large UK study of 0-5 year-old children's app usage found that lower SES children were less likely to have access to apps that cost money, and that parents reported that cost was a barrier to accessing apps (Marsh et al., 2018). On average, these parents may have therefore been less familiar and comfortable with this type of app than higher SES parents may have been and had less time available to use the app with their child and gain familiarity. This may influence the interactions that go on in the home, and the effectiveness of this type of intervention. It could also be that the baseline amount of math that goes on in the home varies by income level, such that introducing this math app was not enough of a change to make a difference (Berkowitz, 2015; Starkey & Klein, 2000).

Less Overall Growth

The children in this study showed a small amount of math growth overall, averaging around half of the amount shown by the children in the original BLT study (Berkowitz et al., 2015). This may indicate that the children in this sample learned less over the course of the school year than those in the high-income sample. There may be school level characteristics, such as the resources available to the school, that vary by neighborhood income level and impact children's learning. Perhaps this math app is effective for families with certain characteristics but not others, and stronger and different kinds of supports are needed to support math learning in the context of lower resourced communities.

Lower Usage

There were not significant usage differences in usage between the two conditions. The average number of days per week that families in this study used the app was around .55 days per week in the math condition and .50 in the reading condition. This was a low amount of usage overall compared to that of the families in the Berkowitz et al. (2015) study. This suggests that lower income families will use a math app, but less often than higher income families. This difference in dosage may at least partly account for the lack of a condition difference. Perhaps in future studies behavioral nudges beyond a weekly reminder may help motivate families to spend more time using the app (Santana, Nussbaum, Carmona & Claro, 2019). Alternatively, the app itself or the tablet device could be made more tuned to the demands of life and preferences particular to this demographic group. For example, we held focus groups in a pilot year of this study with parents from same of the same schools used in this study. Parents reported that they would prefer an app that their child could do alone rather than one that the parent and child were supposed to do together. The parents felt that this would help their child to develop independence. In light of that feedback, perhaps an app that involved the child doing a portion on their own before discussing with the parent would be more desirable.

Parent Math Attitudes

There was not a significant interaction between math anxiety and condition, or a significant main effect of condition or math anxiety on spring Applied Problems score, though parent math anxiety is marginally negatively correlated with spring Applied Problems score. With parent math anxiety not being a significant main effect, and not interacting with condition, it could be that there was no parent math anxiety achievement gap to close in this sample. This is in fitting with Berkowitz, Gibson, and Levine's (in-prep) finding that parent math anxiety was not associated with parent behavior (in that case early math talk) in a lower income sample, though it was in a higher income sample.

As with parent math anxiety, there was not a significant main effect of parent teaching efficacy on spring Applied Problems score. However, Parent Math Anxiety was negatively correlated with parent's feelings of efficacy in their ability to teach their child math. This suggests that math anxious parents are less confident about their teaching abilities, perhaps for good reason, as explored in Study 2. It would be interesting to see if interventions that are able to alleviate the impact of parent math anxiety on child math achievement are also able to increase parents' confidence in their ability to teach their child math. This is an important avenue of future research, because parent's who feel more efficacy in their ability to help their children with academics are more involved with their child's academic pursuits (Banerjee, Meyer & Rowley, 2016).

Future Directions

Future studies should consider further investigating the ways that family math interactions play out in economically diverse samples and consider how best to support low-income families. We cannot assume that an intervention that is successful in one context will be successful in all contexts (Hruschka, Medin, Rogoff, and Henrich, 2018). Interventions that take place in schools or with community partners may also be a way to implement interventions that work for a wider array of students (Eason, in prep).

We can also examine whether parental and child attitudes other than math anxiety that may be associated with math learning. Expectations and values, for example, may be associated with child math growth even when parent math anxiety is not (Shaeffer et al., 2018). Future studies can further explore these links. Future studies can also further explore sources of variability like the involvement of more than one caregiver, neighborhood, and other factors that may interact with parent math anxiety to account for some of the variability in student math growth across first grade.

GENERAL DISCUSSION

Overall Conclusions

In this series of studies, I considered the individual and intergenerational effects of math anxiety and pressure on performance. In study 1, I explored math anxiety and the pressure associated with anticipatory wait time. Replicating previous work, I found that on problems that place a high demand on working memory, individuals with higher math anxiety underperformed as compared to those with lower math anxiety. A novel finding was that individuals in the control group underperformed as compared to those in the drawing intervention group, with a writing intervention group performing at an intermediate level.

In study 2 I addressed what has long been an open question in the literature – what is the nature of the math help that math anxious parents provide their children that undermines children's math learning? (Berkowitz et al., 2015; Maloney et al., 2015). I did this by exploring how parents' trait math anxiety, and situational pressure, impact the ways they interact with their children while doing math. I found that parents who were math anxious or under pressure scored lower on a coding scheme designed to measure teaching quality. Furthermore, adults who were under pressure were more intrusive in their interactions with their children, suggesting a greater proportion of the strategies that the dyad used to solve the problems.

In study 3 I explored the relation of parent math anxiety to child math performance, and a potential intervention, called Bedtime Math, to disrupt the relation between caregivers experiencing math anxiety and their children's learning outcomes. I found that unlike in a higher SES sample, parent math anxiety was not related to children's math performance. However, I did find relations between income and education and child math performance, even within this low SES sample. Additionally, I found that a math app intervention did not work in the same way for a lower-income sample that it had for a higher income sample in a previous study (Berkowitz el al., 2015), and that parent math anxiety and math self-efficacy were related to parent education and income. This may be because the math app and the control app were used much less than in a higher SES sample, with usage even in our low SES sample found to be related to family income and education.

Implications

Overall Implications

Taken together, these studies suggest that anxiety, caused by situational pressure and trait math anxiety, harm performance at both the individual and intergenerational level. Math anxious people not only struggle to perform well individually, they also offer inferior instruction to their children. However, there may be personal and social factors that influence how interventions designed to ameliorate these effects play out in families from different socioeconomic groups. These findings suggest that interventions aimed at addressing the intergenerational effects of math anxiety need to be tailored to the community they are designed to serve. Interventions designed to improve parent/child math interactions may even benefit from being tailored to the dyad, as individual differences in both children and parents impact the math interaction, as found in Study 2.

Math Anxiety and Pressure

Math anxiety was found to harm math performance in study 1, though a drawing intervention helped improve performance across the board as compared to a control condition. In study 2, in which the effects of math anxiety and performance pressure were investigated separately at the intergenerational level, we found main effects but no interaction between math anxiety and pressure. Math anxiety and performance pressure both hurt the overall quality of teaching as measured by the modified RTOP. Further, being in the pressure condition, resulted in parents being more intrusive in a collaborative math task with their children as indexed by a novel Specific Counts coding scheme. However, there was not an interaction between math anxiety and performance pressure in determining behavior in either coding scheme.

From a theoretical standpoint, these studies are consistent with the theory that anxiety, be it due to trait math anxiety, or state anxiety from a pressure induction, ties up working memory, leaving one with less cognitive capacity available to perform working-memory intensive tasks, like solving math problems as in Study 1 or teaching math as in Study 2 (Beilock & Carr, 2005; Ashcraft & Krause, 2007). Effective interventions may be ones that allow individuals to offload their emotions through emotional expression, like drawing a picture of anxious thoughts or feelings. Study 1 suggests that it is the expression of emotion, rather than the formation of a narrative, that has these therapeutic effects, helping to limit the negative impact of anxiety on working memory. In study 3, which did not measure performance pressure, but rather the effect of parent math anxiety on child math performance in an intervention and control condition, parent math anxiety was not found to be related to child math performance in a lower income sample. This suggests that the effects of parent math anxiety, and perhaps any type of anxiety, are sensitive to social context.

Limitations

Each of the studies discussed has limitations on its own, and as a group there are limitations on the conclusions that we can draw from these studies. In Study 1 the number of high and low math anxious participants was not balanced across conditions and those in the control condition did not report feeling more pressure than those in the intervention conditions. Therefore, a replication with a previously used pressure induction may be beneficial. We theorized that anticipatory wait time would create anxiety in our participants, but we may have found stronger results if we gave a drawing or writing intervention right before an important exam as Ramirez and Beilock (2011) did.

Study 2 also had limitations. This study involved coders who were perhaps not completely blind to condition because they saw the answers on the math sheets of the low-pressure group and not on the answer sheets of the high-pressure group, and it is possible that their findings were biased by that knowledge. Furthermore, though this study revealed differences in instruction between high and low math anxious parents, addressing a gap in the literature, the study was not causal and was therefore not able to measure the real outcome of eventual interest, which is how these different parent instruction styles impact future student performance. Further, it is possible that what happens in the lab does not reflect typical homework interactions, which limits the conclusions that we can draw from the study.

Study 3 was underpowered, with only half of the planned data available to be analyzed. Our sample size was further limited by several parents not reporting their income or education level. Study 3 would also benefit from more specific information about why app usage was so low in this sample, and how the app was used when it was. We are exploring, but don't yet know how parents used the app with their children, and how the way that they used the app may have looked different from the usage reported in Berkowitz et al. (2015). This limits the conclusions that we can draw from this data.

As a group, these studies would benefit from testing out the same type of pressure induction and intervention at the individual and intergenerational level. This would help determine if the same factors are in play at both levels. For example, if the pressure induction used in Study 2 and the drawing intervention used in Study 1 were both tried out with adults solving math problems, and parents solving math problems with their children, we could compare the effects of pressure and the benefits of drawing at the individual and intergenerational levels more directly. Perhaps the same interventions that work for individuals work for parent/child dyads, but perhaps not. And, as Study 3 indicates, perhaps the effectiveness of any intervention, and the effects of math anxiety on performance, depend on the social context of the participants' lives.

Future Directions and Open Questions

These studies shed light on what is happening during family math interactions, and they lay the groundwork to answer important questions about the mechanisms at play. For example, in Study 1, what is it that makes a drawing intervention successful? Perhaps making a drawing reduces anxiety, or perhaps it does not change the overall level of anxiety one is feeling but rather prevents rumination because the anxious feelings have already been expressed. Are drawing interventions helpful to the same types of people who are helped by writing interventions? Replications and expansions with more measures, perhaps collecting cortisol and working memory capacity, and using larger and more diverse groups of participants can help to answer these questions (Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011). These answers would clarify the mechanism by which drawing is an effective intervention.

We could also further explore mechanisms at the inter-generational level. For example, future studies can explore why high math anxious parents offer poorer instruction, as seen in Study 2. Is it because high math anxious parents have poorer math skills than lower math anxious parents due to avoiding math whenever possible (Hembree, 1990; Chinn, 2012; Choe, Jennifer, Rozek, Berman & Beilock, 2019)? Or is anxiety about math depleting the working memory of high math anxious parents (Walker & Spence, 1964; Beilock & Carr, 2005; Foley et al., 2017)? Exploring these possibilities would also help to get at the mechanisms in play in Study 3.

Furthermore, future studies could help clarify conflicting results. In Study 2, we found that parents who were anxious or under pressure scored lower on a scale of reformed teaching. However, we did not find that math anxious parents suggested a smaller proportion of strategies, in fact they suggested more, nor disagreed significantly less with their child, in contrast to our pilot study using this same coding scheme. It may be that these divergent findings are due to developmental differences in the way that children of high math anxious parents are treated. Perhaps high math anxious parents are more hands on with younger children than is ideal, and more hands off with older children than is ideal. Future studies that follow the same parent/child dyads over time, or assign problem sets with varying levels of difficulty, would be helpful in confirming this possibility. Future studies could also explore when and how parent math anxiety negatively impacts children's math achievement. It's not clear why parent math anxiety did not negatively impact child achievement in Study 3. Doing a study like Study 2 with an exclusively low-income sample may help to reveal how the relation between parent math anxiety and parental homework help differs in different demographic groups. We are currently conducting a study like this, filming videos of some families who participated in Study 3 using the Bedtime Learning Together app and completing other activities in the lab.

These studies suggest that students and families may benefit from expressing themselves creatively before doing math or practicing math in a low-pressure environment as opposed to a high-pressure environment. Building on the studies presented here, one could design interventions to improve parent/child math interactions. For example, one could investigate how providing parents with teaching support impacts parent/child math interactions, or how allowing parents to express their anxiety through drawing before the math interaction impacts their instructional abilities.

From an applied standpoint, these studies lay the foundation for future exploration of ways to help students, parents, and teachers. By providing insight into the effects of math anxiety and pressure at the individual and intergenerational levels, as well as the social contexts that determine the effects of math anxiety on performance, these studies provide valuable insight for future research and interventions.

APPENDICES

Appendix A: Intervention Task Instructions

Writing Prompt

Please take the next few minutes to write as openly as possible in the space below about your thoughts and feelings regarding the math problems you are about to perform. In your writing, I want you to really let yourself go and explore your emotions and thoughts as you are getting ready to start another set of math problems. You might relate your current thoughts to the way you have felt during other similar situations at school or in other situations in your life. Please try to be as open as possible as you write about your thoughts at this time. Remember, there will be no identifying information on your essay. None of the experimenters, including me, can link your writing to you.

Drawing Prompt

Please take the next few minutes to draw an image (without any words) in the space below that expresses your thoughts and feelings regarding the math problems you are about to perform. In your drawing, I want you to really let yourself go and explore your emotions and thoughts, as you are getting ready to start another set of math problems. You might incorporate images representing the way you have felt during other similar situations at school or in other situations in your life. Please try to be as open as possible. There will be no identifying information on your drawing. None of the experimenters, including me, can link your drawing to you.

Control Prompt

Please sit quietly for the next few minutes until the experimenter returns. When the experimenter returns, you will continue completing the next set of math problems. You will complete several blocks of math problems, similar to the ones you practiced earlier. Please make sure to complete them as quickly and accurately as possible. It is important that you take these tasks seriously so that we can learn more about problem solving.

Appendix B: Parent/Child Task Instructions

Pressure Condition

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 is similar to 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, just 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 our 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.

No Pressure Condition

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: Parent/Child Math 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 _____ ______ _____ _____ _____

a) 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?

Appendix D: Guide to Modified RTOP Scores

Modified RTOP, Modified from Piburn et la., 2000 and Sawada et al., 2002

Quantitative Criteria:
*****Every number subsumes lower numbers; give highest rating that applies**
(1) The instructional strategies respected the child's prior knowledge and preconceptions.
· 0: Parent does not respect the child's prior knowledge. The parent provides very confusing explanations, just gets an answer, or ignores a child who may be able to complete the problem.
· 1:
· 2: Parent respects the child's prior knowledge to an extent. Parent does not break the problem down (simplify) enough for the child, or simplifies the problem too much.
· 3:
· 4: Parent instruction optimally matches the child's knowledge

(2) Parent provided opportunities for child exploration before instruction.
· 0: The parent does not elicit, or elicits very little input from the child.
· 1:
· 2: The parent allows the child to explore the problem
· 3:
· 4: The parent allows the child to explore the problem and supports the child's exploration with explanations or follow-up questions.

(3) The parent's instruction promoted coherent conceptual understanding[BL1] **.**
· 0: The parent's instruction includes nothing conceptual, only counts, or looks at the answer right away without trying to solve the problem.
· 1:
· 2: The parent briefly mentions the concept, or assumes that the child understands the concept, but delves no deeper.
· 3:
· 4: The parent's instruction allows the child to fully understand the word problem, the mathematical operation, and why the operation is the appropriate way to solve the word problem.

(4) The parent had a solid grasp of the subject matter content inherent to the problem
· 0: The parent does not have a solid grasp of the subject matter relevant to the problem.
· 1:
· 2: The parent displays a partial grasp of the subject matter relevant to the problem.
· 3
· 4: The parent has a solid grasp of subject matter relevant to the problem.

(5) Child was actively engaged in critical thinking.
· 0: The child is not actively engaged in critical thinking.
· 1:
· 2: The child is thinking about and actively engaged in the operation; but the operation is embedded in the word problem by the parent.

· 3:
· 4: The child actively engages with the problem conceptually.

(6) In general, the parent was patient with the child.
· 0: The parent interrupts the child multiple times.
· 1:
· 2: The parent does not interrupt the child, but is not responsive to the child's thought process.
· 3:
· 4: The parent is very patient with the child, letting the child explore the problem whether or not the child is on the right path.

[BL1] Understanding the abstract idea presented in the problem and the context in which the operation is being used.

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