Examining the role of different types of pressure in math anxiety and math performance

Kenneth C.E. Hammett

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EXAMINING THE ROLE OF DIFFERENT TYPES OF PRESSURE IN MATH
ANXIETY AND MATH PERFORMANCE

by

KENNETH C. E. HAMMETT

A THESIS

Submitted in partial fulfillment of the requirements
for the degree of a Masters of Art
in
The Department of Psychology
to
The School of Graduate Studies
of
The University of Alabama in Huntsville

Huntsville, Alabama
2017
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THESIS APPROVAL FORM

Submitted by Kenneth C. E. Hammett in partial fulfillment of the requirements for the degree of Masters of Arts in Psychology and accepted on behalf of the Faculty of the School of Graduate Studies by the thesis committee.

We, the undersigned members of the Graduate Faculty of The University of Alabama in Huntsville, certify that we have advised and/or supervised the candidate on the work described in this thesis. We further certify that we have reviewed this thesis manuscript and approve it in partial fulfillment of the requirements for the degree of Masters of Arts in Psychology.

Committee Chair

Department Chair

College Dean

Graduate Dean
ABSTRACT
The School of Graduate Studies
The University of Alabama in Huntsville

Degree __________ Master of Arts _______ College/Dept. _______ Liberal Arts/Psychology

Name of Candidate ______________ Kenneth C. E. Hammett

Title Examining the Role of Different Types of Pressure in Math Anxiety and Math Performance

Math anxiety can negatively impact individuals' performance on math tasks, especially those tasks with high working memory demands. Individuals who are highly math anxious often avoid situations that involve performing math tasks. The level of anxiety experienced by individuals may be affected by different pressure situations. The present study examined the role of different types of pressure (speed, accuracy, or combination [speed + accuracy]) in math anxiety and math performance. Results indicated that experiencing anxiety during a math task has a negative impact on math performance. Results also indicated that speed pressure might be more detrimental to math performance than accuracy pressure. This study provides insight as to what types of pressure are more likely to produce the negative impact of math anxiety on math performance.

Keywords: math anxiety, math performance, pressure

Abstract Approval: Committee Chair ______________ Department Chair ______________ Graduate Dean ______________
ACKNOWLEDGMENTS

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LIST OF ACRONYMS

ANOVA: Analysis of Variance
AVT: Advanced Vocabulary Test
MCI: Memory Controllability Inventory
PCT: Pattern Comparison Task
PDS: Personal Demographic Sheet
PTQ: Post-Task Questionnaire
LIST OF SYMBOLS

$F$: ANOVA

$M$: Mean

$MSE$: Mean Square Error

$\eta_p^2$: Partial eta squared

$p$: Significance

$r$: Pearson Correlation Coefficient

$r^2$: Coefficient of Determination

$SD$: Standard deviation

$SE$: Standard error

$V$: Cramer’s

$X^2$: Chi Square
CHAPTER I

INTRODUCTION

Math anxiety impacts the lives of millions of individuals and can have detrimental effects on math performance (Ashcraft, 2002). Math anxiety has been defined as a negative emotional response characterized by avoidance as well as feelings of stress and anxiety in situations involving mathematical reasoning (Young, Wu, & Menon, 2012). Research has indicated that math anxiety can play a role in the educational and career paths that individuals select, often influencing individuals with high math anxiety to avoid selecting careers in Science, Technology, Engineering, and Math (STEM) fields (Ashcraft, 2002; Meece, Wigfield, & Eccles, 1990). These individuals are often capable of succeeding in these fields, but their negative attitudes toward math and negative math self-efficacy influence them to avoid math whenever possible.

Early Onset of Math Anxiety

Several studies have indicated that individuals can develop math anxiety at an early age (Beilock, Gunderson, Ramirez, & Levine, 2010; Gunderson, Ramirez, Levine, & Beilock, 2012; Ramirez, Chang, Maloney, Levine, & Beilock, 2016). Research has suggested that parents and teachers can project their math anxiety onto children (Beilock et al., 2010; Gunderson, et al., 2012). Research has even suggested that children’s math performance may suffer if they are often helped by a parent with high math anxiety.
Ramirez et al. suggested that math anxiety may reduce children’s use of advanced problem solving strategies that are critical for math achievement and this may lead to a decline in math performance. It is important to acknowledge that children can develop math anxiety at a young age, and that this in turn may negatively impact children’s academic achievement and future employment opportunities.

**The Role of Working Memory**

Researchers have investigated how math anxiety impairs individuals’ math performance. Ashcraft (2002) suggested that math anxiety compromises working memory (WM) and disrupts math performance. The researcher defined WM as the system for conscious, effortful mental processing, and suggested that the effects of math anxiety are tied to those cognitive operations that rely on the resources of WM. Ashcraft and Krause (2007) further evaluated the critical role of WM in math performance and suggested that WM is increasingly involved in problem solving as the numbers in a math problem grow larger. The researchers indicated that individuals solve larger operand problems via non-retrieval processes (i.e., counting, reconstruction). Ashcraft and Krause suggested that individuals adopt these strategies because larger arithmetic problems occur less frequently and are stored in memory at lower levels of strength. Non-retrieval processing is slower and more error prone than memory-based retrieval, and relies far more heavily on the resources of WM.

The impact of math anxiety on individuals with different levels of WM capacity is another topic of interest for researchers. Beilock and DeCaro (2007) performed two experiments examining how individual differences in WM capacity impact the strategies
used to solve complex math problems and how consequential testing situations alter strategy use. In the first experiment the researchers had individuals perform modular arithmetic problems under either low or high-pressure conditions. Modular arithmetic problems are considered ideal stimuli for examining math anxiety and math performance because they are novel (i.e., most participants have not been exposed to these types of problems), allow manipulation of problem difficulty and fluency (i.e., how easy the problems are to process), and tax verbal WM, particularly when the problems are presented horizontally rather than vertically (DeCaro, Rotar, Kendra, & Beilock, 2010). Modular arithmetic problems (e.g., $5 \equiv 2 \pmod{2}$) require individuals to evaluate the problem statement as true or false. To do this, individuals must subtract the second number from the first number and then divide this difference by the mod number. If the resulting number is a whole number then the problem statement is considered to be true. If the resulting number is a fraction, the problem is considered false.

Modular arithmetic can be used to examine how different pressure situations affect math problem-solving ability. Beilock and DeCaro (2007) asked participants to report their problem-solving strategies as they solved modular arithmetic problems. In the low-pressure condition the researchers simply asked individuals to work as quickly and accurately as possible. In the high-pressure condition participants were informed that they had been randomly paired with a team member and that if they both improved their modular arithmetic score by 20%, relative to the preceding practice trials, they would both receive $10. In reality there was no team member, but the participants were informed that their team member had already improved his/her score and that it was up to them to win or lose their team the monetary reward. The participants in the high-pressure
condition were also informed that their performance was being videotaped so that math teachers, students, and professors could examine their performance on this new type of math problem. Beilock and DeCaro found that under low-pressure conditions individuals with higher WM capacity were more likely to use computationally demanding algorithms to solve the problems compared to simpler shortcuts. The researchers found that under high-pressure conditions individuals with higher WM used simpler problem-solving strategies and their performance accuracy suffered. Individuals with lower WM tended to use the simpler problem-solving strategies regardless of the pressure condition. These lower WM individuals also showed little difference in their performance accuracy between conditions.

Additional research examining the impact of math anxiety on children’s problem solving strategies has found that math anxiety reduces the use of advanced problem solving strategies primarily in children with higher WM (Ramirez, Chang, Maloney, Levine, & Beilock, 2016). In contrast children with lower WM tend to show little difference in their use of advanced problem solving strategies regardless of their level of math anxiety. Ramirez et al. suggested that individuals with lower WM tend to rely more on rudimentary problem solving strategies whether they experience high levels of math anxiety or not. These findings indicated that, under pressure situations, individuals with high WM are more negatively impacted by math anxiety than their low WM counterparts.

**Neurological Evidence**

Research utilizing functional magnetic resonance imaging (fMRI) has identified specific areas of the brain associated with math anxiety (Lyons, & Beilock, 2012). Lyons and Beilock presented participants with both a math task and a word task, and brain
activity was recorded using fMRI. Participants were presented a specific cue prior to the onset of the task indicating which task they would perform. The data suggested that the negative relation between math anxiety and math competence arises before math performance begins. Results from the study indicated that increased activity in the frontoparietal regions mitigated math-specific performance deficits for individuals with high math anxiety. This increased activity occurred when high math-anxious individuals simply anticipated doing math. One region identified by the researchers was the bilateral inferior frontal junction (IFJ), an area involved in cognitive control and reappraisal of negative emotional responses. The researchers also concluded that the relation between frontoparietal anticipatory activity and math deficits was mediated by activity in subcortical regions (i.e., caudate, nucleus accumbens, and hippocampus) for high math-anxious individuals during math performance. These subcortical regions are important for coordinating task demands and motivational factors during skill execution.

Additional research has noted that math anxious children, compared to less math anxious children, show hyperactivity in the right amygdala regions (Young, Wu, & Menon, 2012). These regions are important for the processing of negative emotions. The researchers also explained that this increased activity in the amygdala reduces activity in brain regions known to support WM and numerical processing (i.e., dorsolateral prefrontal cortex and posterior parietal lobe). This provides support for the notion that math anxiety may negatively impact math performance by disrupting the processes of individuals’ WM.
Avoidance Tendencies

Research has indicated that highly math-anxious individuals tend to avoid math-related tasks (Ashcraft, 2002). Ashcraft suggested that this avoidance was the most pervasive and unfortunate tendency of highly math-anxious individuals. These individuals take fewer elective math courses, in both high school and college, compared to less math-anxious individuals. Findings from the research performed by Ashcraft suggested that these high math anxious individuals tend to finish math-tasks quickly but inaccurately to end the stressful situation as soon as possible. Ashcraft explained that by speeding through problems, highly math anxious individuals minimize their time and involvement in the task.

Additional research has examined the joint influences of trait variables (i.e., avoidance temperament) and state variables (i.e., evaluative threat) on college students’ math performance (Liew, Lench, Kao, Yeh, & Kwok, 2014). The researchers referred to avoidance temperament as fear and behavioral inhibition, and they described evaluative threat as fear of failure and being viewed as unintelligent. Liew et al. utilized items from the Adult Temperament Questionnaire (ATQ) – Short Form (Evans & Rothbart, 2007) and the Behavioral Inhibition System (BIS) scale (Carver, & White, 1994) to measure temperamental fear and assess avoidance. The researchers found that avoidance temperament and evaluative threat were both associated with low standardized math test scores. It was also found that low course grades were associated with evaluative threat, but not avoidance temperament. Liew et al. suggested that avoidance temperament might predispose individuals to perceive and react to an evaluative situation as ego threatening
and taxing. Findings from the study indicated that evaluative threat hinders not only performance in testing situations, but in math courses as well.

**Hypotheses**

The goal of the present study was to examine the effects of different pressure situations on math anxiety and math performance. Specifically, we aimed to determine whether different pressure situations yield different levels of performance on math tasks, especially for individuals with high math anxiety, and to examine how different pressure situations affect math anxiety relative to those in a control condition with no pressure manipulation implemented. By manipulating the different pressure situations (speed, accuracy, speed + accuracy) we hoped to determine which pressure situation is most detrimental to math performance. We expected that participants’ problem solving performance would vary depending on the assigned condition they were in and how high their math anxiety was. Based on prior research by Ashcraft (2002), we hypothesized that participants (especially those with high math anxiety) in the speed condition would provide answers as quickly as possible (ignoring accuracy) in order to end the task. We expected that the speed condition would produce less anxiety for individuals that were highly math anxious compared to the accuracy and combination conditions because it fits with the natural inclination of highly math anxious individuals to rush through math tasks. We expected highly math anxious participants to experience more anxiety in the accuracy condition because they had to provide correct responses in order to end the stressful situation. We hypothesized that participants would experience the most anxiety in the combination condition because in this situation we pitted the highly math anxious individual’s natural inclination to finish as soon as possible against the need to perform
well. In relation to the research performed by Liew et al. (2014), we expected that individuals’ evaluation of the pressure situation would have an impact on math anxiety and performance. Individuals that perceived the math task as a threat should experience more anxiety and perform worse compared to individuals that viewed the task as a challenge.

Research has suggested that fluency (i.e., subjective ease with which information is processed) and disfluency (i.e., subjective difficulty experienced by participants during cognitive tasks) can influence judgments of learning (JOLs) and performance (Diemand-Yauman, Oppenheimer, & Vaughan, 2011; Oppenheimer & Frank, 2008). The fluency of the problems refers to whether the numbers are related or not, with fluent problems containing related numbers (e.g., 9=6 [mod 3]) and disfluent problems being comprised of unrelated numbers (e.g., 8=2 [mod 3]). Problem difficulty is determined by the WM load of the problem and is typically manipulated by whether the problems contain single or double-digit numbers that require borrowing. We manipulated the fluency and actual difficulty of the modular arithmetic problem statements to allow examination of whether the different pressure situations are more detrimental to performance on certain types of problems.

Metacognitive judgments, such as ease of solving (EOS) judgments and retrospective confidence judgments (RCJs), can be used to evaluate participants’ perceptions of how easy a problem will be to solve and how confident they are that they have solved the problem correctly, respectively (Diemand-Yauman et al., 2011). EOS judgments are typically collected on a 0-100 scale, with higher values indicating that the participant viewed those problems as easier to solve. RCJs are also collected on a 0-100
scale with higher values reflecting greater confidence. We expected participants’ EOS judgments and RCJs to be highest for easy/fluent items. We also expected that difficult/disfluent items would receive the lowest EOS judgments and RCJs. We expected that EOS judgments and RCJs for easy/disfluent and difficult/fluent items would fall in between the other two problem types. Ashcraft and Krause (2007) suggested that multi-step problems demand more WM to accurately solve. For this reason we expected performance to be lowest, especially for individuals who are highly math-anxious, for difficult/disfluent items and highest for easy/fluent items. As with the EOS judgments and RCJs, we expected performance for easy/disfluent and difficult/fluent items to fall between the other two problem types. While these patterns were expected to hold across all four conditions, they were expected to be magnified in the pressure conditions.

Research on the topic of math anxiety has many real-world applications given that students are routinely exposed to pressure inducing testing situations (e.g., SAT/ACT, GRE). Students regularly encounter time and accuracy pressure situations while taking exams which have an impact on their grade or future educational pursuits. Many students believe they could have performed better on these tests if they had more time. Students often talk about how pressure to do well on standardized tests produced anxiety that, in turn, affected their performance. The conditions of the present study align with many real-world situations, and we wanted to empirically examine the impact of these situations on students’ math anxiety and math performance.
CHAPTER II

METHOD

Participants

Participants for the study consisted of students ($N = 146$) enrolled in introductory psychology courses ($M_{age} = 21.01, SD = 4.48; 53.4\%$ female) at The University of Alabama in Huntsville. This number allowed for 35 participants for each condition except in the Combination condition. We collected data from 6 additional participants in the Combination condition ($n = 41$) to obtain a more even distribution of high and low math anxious individuals. Prior research indicated that this number was sufficient to observe effects in this domain using these stimuli (Beilock, 2008). A G*Power 3.1.9 software analysis (Faul, Erdfelder, Lang, & Buchner, 2007) was conducted which indicated that a sample size larger than 76 participants would provide a power of .95 for a medium effect size of .25. Students received 3 activity points toward their grade for their participation in the study. Participants under the age of 18 were required to obtain parental consent in order to participate in the study. Students that were ineligible to participate were dismissed without penalty. Demographic information is presented in Table 1. Mean scores for our external measures (i.e., MCI, AVT, PCT, and Listening Span) are presented in Table 2. All APA ethical guidelines were followed. This study was approved by the Institutional Review Board at The University of Alabama in
Huntsville (refer to Appendix A for the approval letter and Appendix B for the consent form).

<table>
<thead>
<tr>
<th>Ethnicity</th>
<th>Speed</th>
<th>Accuracy</th>
<th>Combination</th>
<th>No Stress</th>
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<tbody>
<tr>
<td>Caucasian</td>
<td>80%</td>
<td>77%</td>
<td>76%</td>
<td>77%</td>
</tr>
<tr>
<td>African American</td>
<td>14%</td>
<td>17%</td>
<td>12%</td>
<td>14%</td>
</tr>
<tr>
<td>Asian</td>
<td>6%</td>
<td>3%</td>
<td>10%</td>
<td>6%</td>
</tr>
<tr>
<td>American Indian/</td>
<td>0%</td>
<td>3%</td>
<td>2%</td>
<td>3%</td>
</tr>
<tr>
<td>Alaskan Native</td>
<td></td>
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*Note: Participants' ethnicity provided as percentages for each Stressor Condition.*
Table 2

Mean Scores for External Measures

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<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
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<tbody>
<tr>
<td>MCI Ability</td>
<td>5.48</td>
<td>0.97</td>
</tr>
<tr>
<td>MCI Improvement</td>
<td>5.14</td>
<td>1.06</td>
</tr>
<tr>
<td>MCI Effort</td>
<td>5.30</td>
<td>1.00</td>
</tr>
<tr>
<td>MCI Decrement</td>
<td>3.18</td>
<td>1.03</td>
</tr>
<tr>
<td>MCI Independence</td>
<td>4.70</td>
<td>0.98</td>
</tr>
<tr>
<td>MCI Alzheimer’s</td>
<td>2.72</td>
<td>0.84</td>
</tr>
<tr>
<td>AVT</td>
<td>15.34</td>
<td>4.89</td>
</tr>
<tr>
<td>PCT</td>
<td>20.92</td>
<td>4.77</td>
</tr>
<tr>
<td>Listening Span</td>
<td>54.23</td>
<td>12.86</td>
</tr>
</tbody>
</table>

Note: Mean scores and standard deviations for each subsection of the Memory Controllability Inventory (MCI), where values closer to 7 represent higher endorsement of the belief, the Advanced Vocabulary Test (AVT, max score 36), the Pattern Comparison Task (PCT, max score 60), and the Listening Span (max score 81).

Design

A 2 (Trial: 1, 2) x 2 (Fluency: fluent, disfluent) x 2 (Problem Difficulty: easy, difficult) x 2 (True/False: true, false) x 2 (Working Memory Capacity: high, low) x 2 (Math Anxiety: high, low) x 4 (Stressor: speed, accuracy, speed + accuracy, control) mixed factorial design was used. Fluency, Problem Difficulty, True/False, and Trial were manipulated within subjects. Stressor, Working Memory Capacity (WMC), and Math Anxiety (MA) were between subjects factors. Correct responses, judgments of difficulty
(i.e., EOSs), judgments of confidence (i.e., RCJs), and the amount of time to complete each problem and trial of problems were measured and compared between conditions.

**Materials**

Many (75%) of the modular arithmetic problems used as stimuli in this study were drawn from those used by Beilock, Kulp, Holt, and Carr (2004). The other 25% of problems were modified to insure equal numbers of each problem type. These stimuli (40 modular arithmetic problems with half easy, half fluent, and half true) and instructions were presented via a computer with use of a program created in house using Python 2.7. The program collected information on the accuracy of participants’ responses as well as the amount of time it took for them to complete each problem. Stimuli were presented in black 48 pt. Arial font on a white background. A questionnaire was used to gather demographic information about the participants. The Memory Controllability Inventory (MCI; Lachman, Bandura, Weaver, & Elliot, 1995), a self-assessment of participants’ memory capabilities, was also used. The MCI consists of 23 statements such as, “If I really want to remember something I can” and asks participants to indicate the extent to which they agree with the statement. The 23 items represent six subscales that measure participants’ beliefs about their present memory ability (MCI Present Ability), whether memory can improve (MCI Potential Improvement), increase upon utility (MCI Effort), memory decline is inevitable (MCI Decrement), they can rely on their memory without the assistance of others (MCI Independence), and how likely they believe they will be to develop Alzheimer’s disease (MCI Alzheimer’s). Participants gave their answers on a Likert scale of 1 to 7 (1= strongly disagree, 7= strongly agree).
We also used the Advanced Vocabulary Test (AVT), a test of participants’ knowledge of word meanings (Ekstrom, French, & Harman, 1976). The AVT presents participants with 36 different words and asks them to select the synonym for the word out of five choices in the 4 min allotted. A Pattern Comparison Task (PCT), which measures processing speed by asking participants to determine whether two patterns of lines are the same or different, was also used (Salthouse, 1996). The PCT asks participants to complete as many pattern comparisons as they can in the 30 s (S = same, D = different) allotted for each of two pages and has a maximum possible score of 60. The Single Item Math Anxiety (SIMA) questionnaire is a one-item questionnaire that assesses participants’ math anxiety on a 1 to 10 Likert scale, where higher values reflect higher math anxiety (Núñez-Peña, Guilera, & Suarez-Pellicioni, 2014). The study performed by Nunez-Pena et al. found that the SIMA produced reliable scores that were consistent with Shortened Math Anxiety Rating Scale (sMARS; Alexander & Martray, 1989) scores. Findings from the study also demonstrated that the SIMA had good test-retest reliability, and suggested that the SIMA scores have good convergent and discriminant validity. The sMARS is a 25-item questionnaire. Therefore, in order to reduce fatigue in our participants we used the SIMA.

DeCaro et al. (2010) explained how horizontally aligned modular arithmetic problems tax verbal working memory. We used the Listening Span Task (Salthouse & Babcock, 1991) to measure participants’ verbal working memory capacity. The Listening Span Task requires participants to answer questions about sentences that are presented to them over speakers, and to remember the final word of each sentence. The Listening Span Task consists of 7 sections with 3 Trials each. Participants were presented
with 1 sentence per Trial in section 1 and the number of sentences presented increased for each section up to 7 sentences per Trial in section 7. Participants had to answer the questions about the sentences correctly for their recall responses to be considered correct, and participants were required to recall the final word of each sentence in the correct order. The first section was used to get the participants familiar with the task and was not scored, so the maximum possible score on the Listening Span task was 81. A post-task questionnaire (PTQ) created in house was used to assess how participants approached the task. The PTQ consisted of 12 questions and provided information regarding how participants evaluated the task (threat or challenge) and how much anxiety they experienced during the math task (see Appendix C).

**Procedure**

Participants were tested in groups of 8 or fewer. Participants’ licenses were checked as they entered the lab to ensure that all were at least 18 years old. Participants who were under 18 required parental consent to participate in the study. Once informed consent was obtained, participants completed the paper-based demographic questionnaire and the MCI. Participants then had 4 min to complete the AVT. Once the AVT was completed participants were presented with the PCT. Participants completed two trials of the PCT in which they had 30 s to complete as many of the 30 comparisons as possible before completing the SIMA questionnaire. The Listening Span Task was administered once all participants were ready. The Listening Span Task instructions and sentences were played over the speakers, and participants reported their answers in the paper-based packet provided to them. When all participants had completed the paper-based tasks, they proceeded on to the math task presented on a computer.
The modular arithmetic math task was administered on the computer. During the math task participants were presented with 40 modular arithmetic problems (10 easy/fluent, 10 easy/disfluent, 10 difficult/fluent, 10 difficult/disfluent). Problem fluency was determined by how related the numbers within the problems were, with fluent problems containing related numbers divisible by one another and disfluent problems containing unrelated numbers. The actual difficulty of the problem statements was determined by the WM demand of the problem statement. Problems with low WM demand were considered to be easy, and problems with high WM demand were considered difficult (see Appendix D). This allowed us to evaluate how perceived and actual difficulty levels interacted with Stressor condition instructions to affect math performance. The problem statements were presented randomly one at a time. Half of the problem statements were true and half were false. Participants first viewed an instruction screen that explained how to perform the task. Although all participants received instructions regarding how to solve modular arithmetic problems mentally, the other instructions participants received depended on the condition to which they were randomly assigned. In the Speed condition participants were informed that if they completed the first trial of problems in 30 s or less, they would be able to skip the next trial of problems. No trials were actually skipped, as we required data from all 40 modular arithmetic problem statements. The instructions were simply designed to yield pressure and ideally enhance performance motivation.

In the Accuracy condition participants were informed that if they answered 18 out of 20 problem statements correctly, they would be able to skip the next trial of problems. As in the Speed condition, no trials were actually skipped.
In the Combination (Speed + Accuracy) condition participants were informed that they must solve 18 out of 20 problems correctly in 30 s or less in order to skip the next trial of problem statements. As in the other pressure conditions, no trials were skipped. Finally, in the control condition, henceforth referred to as the no stress condition, participants received instructions to simply complete all of the problem statements.

After participants had read the instructions, they completed several practice problems to ensure that they had a good understanding of how to solve the math problems. During this instruction phase, participants received feedback regarding whether their response (i.e., true/false) was correct for each of the practice problems. The modular arithmetic problem statements during the practice and problem solving phases were presented horizontally on the computer screen, as research has suggested that problems aligned horizontally are taxing on verbal working memory (Decaro et al., 2010). After participants demonstrated that they understood how to solve the modular arithmetic problems, they were asked to provide ease of solving (EOS) judgments for each problem. Each problem was presented for 2 s in a random order, and participants were asked to rate how easy or difficult they thought each problem was to solve using a scale of 0 to 100 where 0 = difficult and 100 = easy.

After providing EOSs for all 40 problems, they then solved 2 trials, each containing 20 problems under Speed, Accuracy, Speed + Accuracy, or no (control) instructions. Half of the problems presented were easy and half were fluent. After viewing each stimulus participants were expected to solve the problem mentally and indicate whether the problem statement was true or false. Participants indicated their answer by clicking on the true or false button on the computer screen. Participants did
not receive immediate feedback indicating whether or not they solved the problem statement correctly during the problem solving phase. Feedback and any mention of the total number of trials was avoided to increase the likelihood that participants would believe that they could skip a trial if they actually met the criteria.

Finally, participants were asked to provide retrospective confidence judgments (RCJs) estimating their confidence that they successfully solved the problem after each modular arithmetic problem (0 = no confidence and 100 = complete confidence). If the participants met the condition-specific criteria in the first trial for skipping the next trial, they were presented with an instruction screen indicating that they were able to skip the next trial of problem statements and would now begin the final trial. Those that failed to meet the criteria instead viewed an instruction screen indicating that they did not meet the criteria and would now begin the next trial of problems. All participants completed two trials of problems.

Upon completion of both trials of problems, participants completed the PTQ asking them how they approached the task. The PTQ also collected information regarding how much anxiety participants experienced during the math task, and whether they viewed the task as a threat or a challenge. Participants who viewed the math task as a threat were expected to perform worse and experience more anxiety compared to those who viewed the task as a challenge (Liew et al., 2014). Once participants completed the PTQ, they were then debriefed and released.

**Statistics**

SPSS was used to analyze the data. Repeated measures analyses of variance (ANOVAs) were used to assess the effects of Trial, Stressor Condition, WM,
participants' evaluation of the task, and math anxiety ratings on problem solving reaction times (RTs), problem solving performance (i.e., accuracy), and reported anxiety as a function of problem type (i.e., whether the problems are easy/difficult, fluent/disfluent, or true/false). The ANOVAs were also used to assess the influence of fluency and actual problem difficulty on EOS judgments, RCJs, and the absolute accuracy of these judgments. As an alternative to using Bonferroni tests to counteract the problem with multiple comparisons, the alpha level was set at $p < .01$. T-tests were conducted to examine differences in Math Anxiety ratings and Working Memory scores across conditions. The alpha level for the t-tests was set at $p < .05$. A Chi Square test for independence was used to test the relationship between Stressor condition and self-reports of experienced anxiety. Correlations were used to identify any relationships between our external measures (i.e., MCI, AVT, PCT, and Listening Span), reaction time, and problem solving performance. The alpha level for correlations was also set at $p < .05$. 

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CHAPTER III

RESULTS

We performed a median split for the SIMA (Mdn = 5) and Listening Span (Mdn = 56) to classify individuals as having high or low MA and WM. All individuals who scored on or above the median were considered High on both measures. These classifications were used in all of the following analyses to examine the role of WM and MA in math problem solving performance, reaction time, EOS judgments, RCJs, and absolute accuracies. The distribution of high and low MA and WM individuals in each condition was relatively even (Speed: 57% High WM, 43% High MA; Accuracy: 40% High WM, 40% High MA; Combination: 49% High WM, 44% High MA; No Stress: 49% High WM, 49% High MA). The distribution of High/Low MA and WM individuals for each Stressor condition can be seen in Table 3. One-Way ANOVAs were conducted to examine any differences in MA ratings and WM scores between the four groups (i.e., High/High, High/Low, Low/High, and Low/Low). Results revealed a significant main effect for Group for both MA, \( F(3, 142) = 133.79, \text{MSE} = 242.04, p < .001 \), and WM, \( F(3, 142) = 62.90, \text{MSE} = 4561.44, p < .001 \). Mean WM scores and MA ratings for each group are presented in Table 4.

Chi Square tests revealed no significant differences (\( p > .05 \)) in the percentage of High MA or WM individuals in each condition. Also, independent samples t-tests revealed no significant differences (\( p > .05 \)) for MA ratings or WM scores across stressor
conditions. Any differences found in performance, reaction time, etc. were likely the result of our manipulations rather than preexisting differences in these factors. All statistical values were rounded up/down to the nearest hundredth for consistency.

Table 3

*Math Anxiety and Working Memory Distributions*

<table>
<thead>
<tr>
<th>Stressor Combination</th>
<th>Speed</th>
<th>Accuracy</th>
<th>No Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>High MA/Low WM</td>
<td>4</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>High MA/High WM</td>
<td>11</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Low MA/Low WM</td>
<td>11</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Low MA/High WM</td>
<td>9</td>
<td>7</td>
<td>11</td>
</tr>
</tbody>
</table>

*Note:* Distribution of High/Low MA and WM participants in each Stressor condition.

Table 4
Mean Math Anxiety Ratings and Working Memory Scores

<table>
<thead>
<tr>
<th></th>
<th>MA</th>
<th></th>
<th>WM</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>High MA/Low WM</td>
<td>7.38</td>
<td>1.12</td>
<td>44.86</td>
<td>7.61</td>
</tr>
<tr>
<td>High MA/High WM</td>
<td>7.63</td>
<td>1.35</td>
<td>64.23</td>
<td>6.89</td>
</tr>
<tr>
<td>Low MA/Low WM</td>
<td>3.00</td>
<td>1.40</td>
<td>44.78</td>
<td>11.37</td>
</tr>
<tr>
<td>Low MA/High WM</td>
<td>3.06</td>
<td>1.43</td>
<td>64.14</td>
<td>11.37</td>
</tr>
<tr>
<td><strong>5.96</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note:* Means and standard deviations for math anxiety ratings and working memory scores are provided for each group.

**Nominal Data**

A Chi-Square test for independence was performed to examine the relationship between Stressor Condition and self-reports of experiencing anxiety. A significant relationship was found, $X^2 (3, N = 146) = 13.29, p < .01, V = .30$, indicating that participants reported experiencing anxiety at the highest rate in the Combination condition (61%), followed by the Speed (51%) and Accuracy (34%), with the lowest rate in the No Stress (23%) condition. This relationship can be seen in Figure 1.1.
Figure 1.1. Response rates for experiencing anxiety divided as a function of Stressor.

Ease of Solving Judgments

The analysis of EOSs revealed a main effect for Difficulty, $F(1, 130) = 280.30$, $MSE = 234884.80$, $p < .001$, $\eta_p^2 = .68$, indicating that participants perceived easy problems ($M = 88.37$, $SE = 1.55$) as easier to solve than difficult problems ($M = 58.87$, $SE = 1.89$). A main effect for Fluency was also found, $F(1, 130) = 42.26$, $MSE = 5069.41$, $p < .001$, $\eta_p^2 = .25$, indicating that participants believed that fluent problems ($M = 75.79$, $SE = 1.53$) would be easier to solve compared to disfluent problems ($M = 71.45$, $SE = 1.52$). A significant Difficulty by Fluency interaction was also found, $F(1, 130) = 26.26$, $MSE = 3027.46$, $p < .001$, $\eta_p^2 = .17$, indicating that participants rated fluent
problems as easier to solve compared to disfluent problems for both easy and difficult problems. This interaction was more pronounced for difficult problems, with fluent problems \( (M = 62.71, SE = 1.88) \) rated significantly easier compared to disfluent problems \( (M = 55.02, SE = 2.08) \). Easy/fluent problems \( (M = 88.86, SE = 1.58) \) were rated as slightly easier to solve compared to easy/disfluent problems \( (M = 87.88, SE = 1.58) \).

**Reaction Time**

The reaction time of participants (i.e., time in seconds taken to solve problem) was recorded and analyzed using a repeated measures ANOVA. The ANOVA revealed a significant main effect for Trial, \( F(1, 130) = 28.38, MSE = 699.60, p < .001, \eta^2_p = .18 \), indicating that participants took less time to solve the problems in Trial 2 \( (M = 5.96, SE = .24) \) compared to Trial 1 \( (M = 7.09, SE = .28) \). The ANOVA also revealed a significant main effect for Difficulty, \( F(1, 130) = 276.76, MSE = 15393.07, p < .001, \eta^2_p = .68 \), indicating that participants spent more time solving difficult problems \( (M = 9.20, SE = .38) \) compared to easy problems \( (M = 3.85, SE = .14) \). A significant main effect for Stressor was revealed, \( F(3, 130) = 15.94, MSE = 1926.89, p < .001, \eta^2_p = .27 \).

Participants solved problems fastest in the Speed condition \( (M = 4.63, SE = .51) \) followed by the Combination condition \( (M = 5.37, SE = .43) \) and the No Stress condition \( (M = 7.16, SE = .47) \) with reaction times being slowest in the Accuracy condition \( (M = 8.95, SE = .49) \).

The analysis of reaction time produced several interactions. Figure 2.1 reveals the significant interaction between Difficulty and Stressor, \( F(3, 130) = 17.55, MSE = 975.93, p < .001, \eta^2_p = .29 \). Participants consistently spent less time solving easy problems.
compared to difficult problems across conditions. Results also revealed a significant interaction between Trial and True/False, $F(1, 130) = 7.32, MSE = 50.23, p = .008, \eta^2_p = .05$. Participants responded to true ($M = 7.06, SE = .28$) and false ($M = 7.13, SE = .30$) problems at about the same speed in Trial 1, but responded faster to false problems ($M = 5.68, SE = .25$) compared to true problems ($M = 6.23, SE = .27$) in Trial 2.

![Figure 2.1. Mean Reaction time divided as a function of Stressor and Difficulty.](image)

A significant interaction between Difficulty and True/False was also revealed, $F(1, 130) = 19.16, MSE = 160.79, p < .001, \eta^2_p = .13$. For easy problems participants spent less time solving true items ($M = 3.70, SE = .14$) compared to false items ($M = $
4.01, $SE = .17$), but for difficult problems participants spent less time solving false items ($M = 8.80, SE = .39$) compared to true items ($M = 9.59, SE = .40$).

As can be seen in Figure 2.2, there was a significant interaction between Trial, Stressor, and WM, $F(3, 130) = 6.20, MSE = 152.74, p = .001, \eta^2_p = .13$. Reaction times tended to be faster in Trial 2, and varied by condition with the fastest reaction times being seen in the Speed condition and slowest reaction times seen in the Accuracy condition. High WM participants also tended to respond more quickly than Low WM participants.

Results also revealed a significant interaction between Trial, Difficulty, Stressor, and WM, $F(3, 130) = 6.09, MSE = 86.40, p = .001, \eta^2_p = .12$, which can be seen in Figure 39.

**Figure 2.2.** Mean Reaction Time divided as a function of Trial, Working Memory, and Stressor.
2.3. Reaction times for low WM individuals were consistently slower than those for high WM individuals except for difficult problems in the Accuracy condition during Trial 1.

![Graph](image)

*Figure 2.3. Mean Reaction Time divided as a function of Stressor, Trial, Difficulty, and Working Memory.*

Results also revealed a significant interaction between Difficulty, True/False, Fluency, and WM, $F(1, 130) = 7.67$, $MSE = 43.32$, $p = .006$, $\eta^2_p = .06$, which can be seen in Figure 2.4. Low WM participants responded slower than high WM participants, and both responded much slower to difficult compared to easy problems.
Problem Solving Performance

Results from the repeated measures ANOVA examining performance revealed a main effect for Difficulty, $F(1, 130) = 102.31, MSE = 8.79, p < .001, \eta_p^2 = .44$, indicating that participants' performance was better for easy problems ($M = .89, SE = .01$) compared to difficult problems ($M = .77, SE = .01$). Results also revealed a main effect for True/False, $F(1, 130) = 33.62, MSE = 4.32, p < .001, \eta_p^2 = .21$, which indicated that performance for false problems ($M = .88, SE = .01$) was better than true problems ($M = .79, SE = .02$). A main effect for Fluency, $F(1,130) = 13.36, MSE = .57, p = .001, \eta_p^2 = .09$, indicated that participants' performance was better for fluent problems ($M = .85, SE$...
= .01) compared to disfluent problems (\(M = .81, SE = .01\)). A main effect for Stressor was found, \(F(3, 130) = 5.97, MSE = 1.89, p = .001, \eta^2_p = .12\), indicating that performance was best in the Accuracy condition (\(M = .90, SE = .03\)) followed by the No Stress condition (\(M = .85, SE = .02\)) and the Combination condition (\(M = .80, SE = .02\)), with performance being worst in the Speed condition (\(M = .77, SE = .03\)).

Results from the ANOVA also revealed several interactions. An interaction between Trial and True/False was found, \(F(1, 130) = 9.55, MSE = .35, p = .002, \eta^2_p = .07\), and indicated that participants performed better on false problems in Trial 2 (\(M = .90, SE = .01\)) compared to Trial 1 (\(M = .85, SE = .02\)) while performance on true items did not differ between Trial 1 (\(M = .79, SE = .02\)) and Trial 2 (\(M = .79, SE = .02\)). An interaction between Difficulty and True/False was also found, \(F(1, 130) = 34.03, MSE = 2.82, p < .001, \eta^2_p = .21\). Participants’ performance was almost equal for easy problems that were false (\(M = .90, SE = .01\)) compared to true (\(M = .89, SE = .02\)), but there was a significant difference between false (\(M = .85, SE = .014\)) and true problems (\(M = .69, SE = .02\)) that were difficult. The interaction between True/False and Fluency, \(F(1, 130) = 16.81, MSE = 1.41, p < .001, \eta^2_p = .11\), revealed that for true items performance was better for fluent problems (\(M = .83, SE = .01\)) compared to disfluent (\(M = .74, SE = .02\)) while for false items performance was better for disfluent problems (\(M = .88, SE = .01\)) compared to fluent (\(M = .87, SE = .01\)).

The interaction between Trial, Difficulty, and Fluency, \(F(1, 130) = 12.24, MSE = .38, p = .001, \eta^2_p = .09\), can be seen in Figure 3.1. Participants performed better in Trial 2 compared to Trial 1 on all problems except those that were easy/fluent.
Figure 3.1. Mean Performance divided as a function of Difficulty, Fluency, and Trial.

Retrospective Confidence Judgments

Results from the analysis of RCJs revealed a main effect for Difficulty, $F(1,130) = 99.60, \text{MSE} = 67319.18, p < .001, \eta_p^2 = .43$, indicating that individuals were more confident that they answered easy problems correctly ($M = 86.25, SE = 1.88$) compared to difficult problems ($M = 75.08, SE = 2.03$). The analysis also revealed several interactions including a Difficulty by Stressor interaction, $F(3,130) = 4.91, \text{MSE} = 3316.35, p = .003, \eta_p^2 = .10$, indicating that participants were more confident for easy problems compared to difficult problems. Participants were more confident for easy ($M = 91.99, SE = 3.87$) compared to difficult problems ($M = 84.99, SE = 4.18$) in the Accuracy condition, and also for easy ($M = 86.51, SE = 3.70$) compared to difficult problems ($M = 79.62, SE = 4.00$) in the No Stress condition. This effect was more pronounced for easy problems ($M = 80.88, SE = 4.03$) compared to difficult problems ($M$
in the Speed condition, and also for easy problems \((M = 85.63, SE = 3.44)\) compared to difficult problems \((M = 71.98, SE = 3.72)\) in the Combination condition. Results from the analysis also revealed a Trial by Difficulty interaction, \(F(1,130) = 12.26, MSE = 1929.70, p = .001, \eta^2_p = .09\). Participants were more confident for easy items compared to difficult items in both Trials; however, confidence for easy items was lower for Trial 2 \((M = 85.44, SE = 2.07)\) compared to Trial 1 \((M = 87.07, SE = 1.90)\), while confidence for difficult items was higher for Trial 2 \((M = 76.16, SE = 2.24)\) compared to Trial 1 \((M = 74.01, SE = 2.01)\).

Results from the study also revealed a significant interaction between Trial, Difficulty, Fluency, Stressor, and MA, \(F(3,130) = 5.24, MSE = 381.74, p = .002, \eta^2_p = .11\), which can be seen in Figure 4.1. Low MA individuals tended to be more confident than high MA individuals except in the Speed condition and for difficult problems in the Combination condition. A significant interaction between Trial, Difficulty, Fluency, WM, and MA was also found, \(F(1,130) = 8.30, MSE = 603.87, p = .005, \eta^2_p = .06\). This interaction can be seen in Figure 4.2. High WM low MA individuals tended to be the most confident. High MA individuals tended to be less confident than their low MA counterparts, and were least confident for difficult problems in Trial 1.
Figure 4.1. Mean RCJs divided as a function of Stressor, Trial, Difficulty, Fluency, and Math Anxiety.
Absolute Accuracy

Absolute accuracy is calculated by multiplying performance scores by 100 so that they are on the same scale as RCJs. Performance scores are then subtracted from RCJs to obtain the absolute accuracy (i.e., 0 = perfect accuracy, negative numbers = under-confident, positive numbers = over-confident). A main effect for Fluency was revealed, $F(1,130) = 29.26$, $MSE = 14256.00$, $p < .001$, $\eta^2_p = .18$. Participants were slightly over-confident for fluent problems ($M = .23$, $SE = 1.89$) and under-confident for disfluent problems ($M = -4.91$, $SE = 1.71$). Several significant interactions were found including Trial by True/False, $F(1,130) = 24.18$, $MSE = 16211.96$, $p < .001$, $\eta^2_p = .16$. For true items participant went from being over-confident in Trial 1 ($M = 2.78$, $SE = 2.02$) to
being under-confident in Trial 2 ($M = -5.13$, $SE = 1.96$). While participants were under-confident for false items in both Trials, they were more under-confident in Trial 1 ($M = -5.04$, $SE = 1.87$) compared to Trial 2 ($M = -1.98$, $SE = 2.25$).

Results also revealed a Trial by Fluency interaction, $F(1,130) = 34.16$, $MSE = 33461.57$, $p < .001$, $\eta_p^2 = .21$. Participants were under-confident for fluent items in Trial 1 ($M = -2.50$, $SE = 1.80$) and over-confident for fluent items in Trial 2 ($M = 2.95$, $SE = 2.45$). The opposite occurred for disfluent items with participants being over-confident in Trial 1 ($M = .24$, $SE = 1.95$) and under-confident in Trial 2 ($M = -10.06$, $SE = 1.94$). A significant interaction between Difficulty and Fluency was found, $F(1,130) = 39.38$, $MSE = 25982.20$, $p < .001$, $\eta_p^2 = .23$. For easy items participants were under-confident whether the problem was fluent ($M = -4.03$, $SE = 1.92$) or disfluent ($M = -2.23$, $SE = 1.87$). For difficult items participants were over-confident for fluent problems ($M = 4.49$, $SE = 2.28$) and under-confident for disfluent problems ($M = -7.59$, $SE = 1.97$). A significant interaction between True/False and Fluency was also found, $F(1,130) = 23.34$, $MSE = 18950.14$, $p < .001$, $\eta_p^2 = .15$. Participants were under-confident for true items whether they were fluent ($M = -1.57$, $SE = 1.91$) or disfluent ($M = -1.78$, $SE = 2.01$), but for false items participants were over-confident when problems were fluent ($M = 2.02$, $SE = 2.14$) and under-confident when problems were disfluent ($M = -9.04$, $SE = 1.86$).

As can be seen in figure 5.1, an interaction between Trial, Difficulty, and True/False was found, $F(1,130) = 10.17$, $MSE = 4564.05$, $p = .002$, $\eta_p^2 = .07$. Participants were over-confident for true items (more so for difficult problems) in Trial 1, but became under-confident in Trial 2. Participants were under-confident for false items in both Trials.
Correlations

Correlations were analyzed to examine any relationships between our external measures (i.e., MCI, AVT, PCT, and Listening Span) and performance. Results indicated a negative correlation between AVT scores and reaction time for both Trial 1, \( r(145) = -.18, p = .03, r^2 = .03 \), and Trial 2, \( r(145) = -.17, p = .04, r^2 = .03 \). Reaction time decreased as AVT scores increased. Results also indicated a positive correlation between AVT score and problem solving performance in Trial 1, \( r(145) = .18, p = .03, r^2 = .03 \). Problem solving performance in Trial 1 increased as AVT score increased. This correlation was not significant for Trial 2. No other correlations were significant.
We were also interested in examining whether participants’ perceptions of the math task might influence their problem solving performance. To investigate this possibility, we utilized participants’ responses on the PTQ question 5 to examine whether performance would differ for those who reported viewing the task as a threat or challenge versus those who said neither. A repeated measures ANOVA was used to analyze their responses and problem solving performance. The analysis examining the impact of participants’ evaluations of the situation (i.e., Threat, Challenge, or Neither) on performance was not significant, but participants performed worse when they viewed the task as a threat ($M = .76, SE = .05$) compared to a challenge ($M = .84, SE = .02$) and neither ($M = .82, SE = .03$). Only 9 participants reported viewing the task as a threat while 94 viewed the task as a challenge and 43 viewed the task as neither. This discrepancy is likely the reason the analysis did not reach significance.
CHAPTER IV

DISCUSSION

Research regarding math anxiety has shed light on the negative impact of stressor situations on performance, particularly for highly math-anxious individuals. The purpose of this study was to examine the role of different stressor situations in math performance and math anxiety. Results from this study provide additional support for the negative effects of math anxiety on math performance, especially in stressor situations (Beilock & DeCaro, 2007).

Ease of Solving Judgments

The current study first assessed participants' EOS judgments. Findings suggested that individuals perceive difficult problems as harder to solve compared to easy problems. Participants also perceived fluent problems as easier to solve compared to disfluent problems. If easy items are considered more fluent than difficult items, both of these results provide support for the notion that fluency influences individuals’ metacognitive judgments (Diemand-Yauman et al., 2011). Our hypothesis was confirmed that easy/fluent problems received the highest EOS judgments followed by easy/disfluent, difficult/fluent, and finally difficult/disfluent received the lowest EOS judgments. Again, this appears to support the idea that easy problems may appear to be more fluent than difficult problems regardless of the fluency manipulation. The fluency
of an item may be relative to what it is compared to. In other words our easy items, whether they were manipulated to be fluent or disfluent, may have appeared as more fluent than the difficult items, and thus received higher EOS judgments.

EOS judgments also appeared to be generally higher in the Accuracy and No Stress conditions compared to the Speed and Combination stressor conditions. This indicated that stress levels may have been higher for the latter, and thus decreased EOS judgments. This also provides support for the research performed by Lyons and Beilock (2012). The researchers suggested that the negative relation between math anxiety and math competence arises before participants begin solving problems. If this is true it also indicates, with regards to the current study, that when individuals are instructed to focus on accuracy without time constraints they do not experience the same level of anxiety as when presented with speed pressure.

**Reaction Time**

The current study also assessed the amount of time participants spent solving the modular arithmetic problems. Our hypothesis that in the Speed condition highly math anxious individuals responded faster than individuals with low MA was not confirmed. While highly MA individuals did respond faster than low MA individuals in the Speed condition, this result was not significant at the $p < .01$ level. Ashcraft (2002) suggested that high MA individuals often rush through math tasks in order to end the stressful situation as soon as possible. Our extra incentive of skipping a set of problems may have provided even more motivation for these individuals to rush through the task ignoring accuracy. Overall reaction times were fastest in the Speed condition, followed by the Combination and No stress conditions, with the slowest reaction times recorded in the
Accuracy condition. Participants also responded faster for fluent and easy items compared to disfluent and difficult items. This is understandable considering fluent items should be easier and require less time to solve than disfluent items. Also, difficult or larger operand problems should require more time to accurately solve (Ashcraft & Krause, 2007). High WM individuals tended to respond faster than those with low WM. These high WM individuals are likely more efficient in solving difficult problems than low WM individuals, which may have led to their overall faster performance.

Participants also tended to respond faster in Trial 2 compared to Trial 1. Practice effects could explain this. Results also revealed a positive correlation between AVT scores and reaction time. Individuals with higher AVT scores tended to solve the problems more quickly. These individuals may have acquired knowledge over the years that allowed them to solve the problems faster than those with low AVT scores given that the AVT is thought to measure crystallized intelligence.

**Problem Solving Performance**

The main focus of the study was to examine the influence of math anxiety and different pressure situations on math performance. As expected, performance on the math task varied across conditions. Performance was best for the Accuracy condition, followed by the No Stress and Combination conditions, with performance being the worst in the Speed condition. This result did not coincide with the pressure experienced in each condition. Respondents reported experiencing anxiety at the highest rate in the Combination condition, followed by the Speed and Accuracy conditions, with the lowest rate occurring in the No stress condition. This suggests that time constraints may have
more of a negative influence on math performance than does pressure to answer
correctly.

Research has shown that individuals with high WM are more negatively
impacted by pressure situations than those with low WM (Ramirez, Chang, Maloney,
Levine, & Beilock, 2016). Results from our study did not match these outcomes. High
WM individuals tended to perform better than low WM individuals except in the Speed
condition. This does not support findings by Beilock and DeCaro (2007). Also, low MA
individuals tended to perform better than high MA individuals except in the Combination
condition. Results from the study performed by Beilock and DeCaro indicated that
highly math-anxious individuals with high WM revert to using simple shortcuts
(sacrificing accuracy) to solve math problems in high-pressure situations. The fact that
all participants’ performance tended to drop in the Combination and Speed conditions
compared to the No Stress condition suggests that even participants that do not identify
themselves as math anxious may experience the negative effects on math performance
associated with math anxiety. Although participants with high WM tended to outperform
low WM individuals, it did appear that math anxiety compromised WM by consuming
cognitive resources necessary for coordinating task demands as suggested by Ashcraft
(2002).

Several other factors were found to influence problem solving performance,
including Fluency, Difficulty, and whether problems were True/False. Research has
suggested that fluency can influence metacognitive judgments and performance
(Diemand-Yauman et al., 2011; Oppenheimer & Frank, 2008). In our study participants
performed better on fluent problems compared to disfluent problems. Participants’
performance was also better for easy problems compared to difficult problems. As mentioned earlier, easy problems should appear more fluent and facilitate faster, more accurate processing. Another interesting finding was that performance was better for disfluent problems compared to fluent problems when the problems were false, and the opposite when the problems were true. Previous research examining how perceptual fluency affects truth judgments found that fluent statements were judged as more probably true than were disfluent statements (Hansen, Dechene, & Wanke, 2008). This effect only occurred when high fluency meant a change from previous fluency. Problems for our study were presented randomly and were half fluent and half difficult, so this change in fluency likely occurred often in our study. While the study performed by Hansen et al. involved statements instead of arithmetic problems, it is possible that the same effect occurred. Hansen et al. suggested that individuals monitor changes rather than states, and that changes in fluency may have a more pronounced impact on truth ratings than absolute fluency. Participants may also perceive true/fluent as congruent and false/disfluent as congruent. If participants were more likely to select false for disfluent problems, this could have led to the differing performance for true/fluent and false/disfluent problems.

Research has suggested that participants’ evaluation of a situation can influence performance (Liew et al., 2014). The researchers suggested that evaluative threat hinders math performance in testing situations. While our analysis of participants’ evaluations did not reach significance, participants that viewed the task as a threat did perform worse than those who viewed the task as a challenge or neither. Of the 9 participants who viewed the situation as a threat, 8 rated themselves as highly math anxious. High MA
individuals may be more prone to viewing a math task as a threat than are Low MA individuals. Participants who view the situation as a threat likely experience more anxiety and their performance suffers because of this. Results from the analysis of our external measures revealed a positive correlation between AVT scores and performance in Trial 1. Ashcraft and Krause (2007) suggested that individuals solve larger operand problems via non-retrieval processes because larger arithmetic problems occur less frequently and are stored in memory at lower levels of strength. Individuals with high AVT scores may have acquired more experience solving larger operand problems, and may be better prepared to solve these problems.

**Confidence Judgments and Absolute Accuracy**

The current study also examined the influence of several factors on confidence ratings. Results indicated that participants were more confident for fluent problems compared to disfluent problems, and for easy problems compared to difficult problems. As noted, fluency has been found to influence individuals’ metacognitive judgments and performance (Diemand-Yauman et al., 2011). The researchers suggested that disfluent items signal to individuals that more elaborative cognitive processing is necessary. Fluent modular arithmetic problems may have appeared easier to calculate and thus received higher RCJs compared to disfluent items. As was suggested for EOS judgments, easy problems may appear more fluent than difficult problems and produce similar RCJs as fluent compared to disfluent problems. The absolute accuracy results appear to support this with participants being slightly over-confident for fluent problems and under-confident for disfluent problems. The interaction between Trial and Fluency revealed that participants began the task being under-confident for fluent items and over-
confident for disfluent items in Trial 1. This was reversed in Trial 2 after participants had a chance to solve some modular arithmetic problems.

Results from the study indicated that high MA individuals tended to provide lower RCJs compared to low MA individuals except in the speed condition. This may have occurred because high MA individuals' natural inclination is to end the task as quickly as possible, so the Speed instructions did not have the same impact on RCJs as the Accuracy or Combination instructions (Ashcraft, 2002). Absolute accuracies indicated that high MA individuals tended to be under-confident except for fluent/false problems. Participants with high WM also tended to provide higher RCJs compared to low WM individuals except in the Speed condition. Beilock and DeCaro (2007) explained the importance of WM for solving these modular arithmetic problems. These high WM individuals may have had more confidence in their ability to accurately solve the problems compared to low WM individuals, except when they believed they did not have adequate time to accurately solve the problems. Although high WM individuals tended to provide higher RCJs, absolute accuracies indicated that they were more under-confident for difficult/disfluent problems than were low WM individuals.

Participants' confidence ratings appeared to match overall performance with the highest RCJs occurring in the Accuracy condition followed by the No Stress and Combination conditions, and lowest RCJs occurring in the Speed condition. Absolute accuracies indicated that participants were most under-confident for false/disfluent problems in the Speed and Combination conditions. It is possible that the participants were aware of the potentially increased anxiety levels in the Combination and Speed conditions, and may have been aware of the negative impact of this anxiety on their
performance, as has been suggested by previous research (Ashcraft & Krause, 2007; Beilock & DeCaro, 2007). If this is true, then it may be possible for instructors to teach students to recognize when stress is hindering their performance and adjust their problem solving procedures accordingly. By teaching techniques to deal with stressful situations appropriately, instructors may be able to increase performance in these situations.

Results also indicated that participants were more confident in Trial 2 compared to Trial 1. It appears that participants became more confident after being able to solve some of the modular arithmetic problems. As with most tasks, practicing appears to increase both performance and confidence.

Summary

The present study provides insight as to the impact different stressor situations have on math anxiety and math performance. It also revealed how problem difficulty and fluency can also influence performance. The negative impact of anxiety on math performance in this study may not have been as pronounced as in real world situations. Participants may not have experienced as much pressure to perform well as they would in a classroom setting. The impact of anxiety on math performance is likely much greater in actual testing situations. It appeared that time pressure was more detrimental than accuracy. The findings from the current study can provide information on what aspects of standardized testing could be altered to increase performance, specifically for those who experience math anxiety. One suggestion would be to test students more frequently with each test covering less material so that students feel they have adequate time to complete the task. Once students feel they do not have enough time to complete the task they may spend less time on each subsequent problem. Spending less time on problems
likely hinders performance and this dilemma continues as students try to rush to complete the task.

One limitation of the current study was that our time constraint in the Speed and Combination conditions was extreme. Participants were instructed to try to solve all problems in 30 s or less. This was an impossible task if they were trying to answer the problems accurately. Future research should examine the limits of time constraints to determine at what point the time constraint induces anxiety. Researchers should also continue to study math anxiety in actual classroom settings because it is very difficult to replicate the pressure felt during an actual exam.
January 30, 2017

Dr. Jodi Price Ph.D.
Associate Professor of Psychology
University of Alabama in Huntsville

Dear Dr. Price,

The UAH Institutional Review Board of Human Subjects Committee has reviewed your proposal, *Examining the Role of Different Types of Pressure in Math Anxiety and Math Performance*, and found it meets the necessary criteria for continued approval. Your proposal seems to be in compliance with this institution's Federal Wide Assurance (FWA) 00019998 and the DHHS Regulations for the Protection of Human Subjects (45 CFR 46).

Please note that this approval is good for one year from the date on this letter. If data collection continues past this period, you are responsible for processing a renewal application a minimum of 60 days prior to the expiration date.

No changes are to be made to the approved protocol without prior review and approval from the UAH IRB. All changes (e.g. a change in procedure, number of subjects, personnel, study locations, new recruitment materials, study instruments, etc) must be prospectively reviewed and approved by the IRB before they are implemented. You should report any unanticipated problems involving risks to the participants or others to the IRB Chair.

If you have any questions regarding the IRB's decision, please contact me.

Sincerely,

William Wilkerson
IRB Chair
Dean, Honors College
APPENDIX B

Consent/Assent Form

Dr. Jodi Price
Lifelong Learning Lab
(256) 824-4590

The University of Alabama in Huntsville
Department of Psychology
Huntsville, Alabama 35899

Contact Information:
Dr. Jodi Price: (256) 824-3321

Purpose of Study

The primary goal of this study is to examine how people approach solving a particular type of math problems under instructions that stress speed, accuracy, or both speed and accuracy. Results from this research study and others like it that are conducted in our lab have the potential not only to increase our current understanding of learning, but also to raise new questions that will further advance our science. You are being asked to participate in this study. We are asking that you commit 90 minutes of your time for this study. You will be given 3 research activity points for your participation.

Experimental Procedures to be Followed

You will be asked to complete a few tasks in this experiment. The main task will require you to attempt to solve math problems to the best of your ability. Immediately after solving each problem you will be asked to estimate the likelihood you successfully solved the math problem. The other tasks that you will be asked to complete will be administered via paper and pencil and will ask you to provide some basic demographic information, answer a survey about your memory, and complete a vocabulary test, and provide some information about your experience with the study.

Confidentiality
All of your answers to questions and responses will be kept strictly confidential. To protect the confidentiality of this information, we will assign you a code number that will only be known to the members of the research project. All of the information that you provide us today will be marked with the code number, not your name, and the information will be stored in a computer for analyses using only your code number for identification. The information is being collected solely for the purposes of understanding math learning. In order to ensure that this research is being conducted in the proper way, the IRB at The University of Alabama in Huntsville may review the data we collect. However, they are the only people outside of this research study that will have access to these data. No indication of your math skills will be given to anyone else. We want you to be completely confident that you may feel free to answer all questions without concern that it may affect you in any way.

We are grateful for your willingness to participate in the research project. We need your help because you and others will help us to accomplish our aims mentioned above. This study is completely voluntary. You may choose to participate in this study, in which case you will receive 3 research activity points for participating. We want you to know, however, that you are free to change your mind and withdraw from this research at any time. There will be no penalties for doing so; you will not lose any credit for withdrawing early from a session, but will not earn any credit either. You are free to earn activity points by completing research studies listed on SONA other than this one or other non-research assignments. If there are any problems that arise during your participation, please feel free to contact the project director, Dr. Jodi Price (256-824-3321; jodi.price@uah.edu), or Dr. William Wilkerson, IRB Chair (256-824-6000; irb@uah.edu), at The University of Alabama in Huntsville to discuss any questions or concerns you have regarding your rights as a participant. Again, we are grateful for your help and want to make sure that your participation is a pleasant experience. Following your participation, you will be provided with an explanation of why this study was conducted.

Discomfort and Risks

There are no major physical risks involved in this study. There is a minor risk of eyestrain from reading the questionnaires and words on the computer screen. However, any eyestrain should be no more than is normally experienced when using a computer or pencil and paper. Should you feel at any time that you need additional rest, please ask the person assisting you.

Potential Benefits

This study will provide knowledge about factors that may influence how people approach math learning. This knowledge could be of potential benefit to others through our search for understanding of these processes.

Contact Person

Please feel free to contact Dr. Jodi Price (jodi.price@uah.edu) if you have any questions or concerns about this research study.
By signing this form, you agree to take part in this research study. Your signature indicates that you read the information above and understand it completely. You also indicate that the researchers answered all of your questions to your satisfaction.

Printed Name: __________________________          Date: __________________

Signature: _________________________________

Signature of Parent or Guardian: ________________________________
(If under the age of 18)

Researcher signature: __________________________ Date: __________________
APPENDIX C

POST TASK QUESTIONNAIRE

This questionnaire is designed to assess how you solved the math problems during the experiment. Please answer the following questions.

1. How important is it to you to perform well in math courses (1 = not important at all, 7 = very important)?
   
   1  2  3  4  5  6  7

2. How important was it for you to perform well in this task (1 = not important at all, 7 = very important)?
   
   1  2  3  4  5  6  7

3. Did the computer instructions mention that you would be under time or accuracy pressure while solving the math problems?
   
   A. Time Pressure
   B. Accuracy Pressure
   C. Time and Accuracy Pressure
   D. None

3b. If you selected option C in question 3, which were you more concerned with?
   
   A. Time Pressure
   B. Accuracy Pressure
   C. I was equally concerned with both
   D. Not applicable

4. Did the instructions cause you to experience any feelings of anxiety?

   YES  NO
4b. If you answered yes to question 4, what caused you to feel anxious?

________________________________________________________________________
________________________________________________________________________

5. Did you view the math problems as (please circle one)
   A. A Threat
   B. A Challenge
   C. Neither

Please complete the questions on the last page. Turn over ⇒ ⇒ ⇒ ⇒

6. Did some of the math problems appear easier to you than others?
   YES                      NO

6b. If so, what characteristics of the math problems made them appear easier?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

7. What strategies did you use to solve the math problems?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

8. Do you believe your performance on this task is reflective of your math ability?
   YES                      NO

9. Had you previously been exposed to this type of modular arithmetic math problem before?
   YES                      NO

Thank you for completing the questionnaire.

Please notify the experimenter that you have finished.

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APPENDIX D

Example of Easy/Difficult, True/False and Fluent/Disfluent Problems

<table>
<thead>
<tr>
<th>Easy Problems (Low WM)</th>
<th>True/Fluent</th>
<th>True/Disfluent</th>
<th>False/Fluent</th>
<th>False/Disfluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>9=6 (mod 3)</td>
<td>8=2 (mod 3)</td>
<td>3=2 (mod 2)</td>
<td>9=4 (mod 2)</td>
<td></td>
</tr>
<tr>
<td>2=1 (mod 1)</td>
<td>7=2 (mod 5)</td>
<td>9=1 (mod 3)</td>
<td>4=1 (mod 2)</td>
<td></td>
</tr>
<tr>
<td>3=2 (mod 1)</td>
<td>3=1 (mod 2)</td>
<td>3=1 (mod 3)</td>
<td>5=1 (mod 3)</td>
<td></td>
</tr>
<tr>
<td>4=2 (mod 2)</td>
<td>4=1 (mod 3)</td>
<td>4=2 (mod 4)</td>
<td>4=3 (mod 2)</td>
<td></td>
</tr>
<tr>
<td>5=3 (mod 1)</td>
<td>5=2 (mod 3)</td>
<td>5=3 (mod 3)</td>
<td>5=3 (mod 4)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Difficult Problems (High WM)</th>
<th>True/Fluent</th>
<th>True/Disfluent</th>
<th>False/Fluent</th>
<th>False/Disfluent</th>
</tr>
</thead>
<tbody>
<tr>
<td>10=5 (mod 5)</td>
<td>17=9 (mod 4)</td>
<td>10=2 (mod 10)</td>
<td>17=9 (mod 5)</td>
<td></td>
</tr>
<tr>
<td>25=5 (mod 2)</td>
<td>26=11 (mod 3)</td>
<td>25=2 (mod 2)</td>
<td>26=11 (mod 4)</td>
<td></td>
</tr>
<tr>
<td>33=30 (mod 3)</td>
<td>37=16 (mod 7)</td>
<td>33=13 (mod 3)</td>
<td>37=16 (mod 4)</td>
<td></td>
</tr>
<tr>
<td>44=22 (mod 2)</td>
<td>43=18 (mod 5)</td>
<td>44=14 (mod 4)</td>
<td>43=18 (mod 8)</td>
<td></td>
</tr>
<tr>
<td>50=10 (mod 5)</td>
<td>51=19 (mod 4)</td>
<td>50=15 (mod 15)</td>
<td>51=19 (mod 7)</td>
<td></td>
</tr>
</tbody>
</table>
REFERENCES


