Exploring Math Anxiety, Working Memory, Timed Testing, Math Performance, and Physiological Effects on College Students

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Report Submitted to:

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Abstract

In the U.S alone, an estimated 25 percent of university students and 80 percent of community college students report experiencing moderate to high levels of math anxiety when engaging in math-related tasks. Math anxiety has been associated with feelings of tension, nervousness, apprehension, and interference with the ability to focus during math calculating tasks. Previous research has shown that working memory capacity and math anxiety negatively influence math performance. However, claims that timed tests negatively impact math performance and increase math anxiety have been made despite a lack of evidence. This study examines how working memory, math anxiety, math accuracy, and heart rate interact to affect math accuracy in timed and untimed testing conditions. To investigate these relations, two studies were developed. First, a behavioral study examined how working memory and math anxiety affects math accuracy in timed and untimed testing conditions. Second, an exploratory psychophysiological study was also conducted to investigate the influence working memory, math anxiety, and heart rate have on students' math accuracy when in timed and untimed testing conditions. Results demonstrated that, as anticipated, students who were assigned to the untimed condition performed better than those in the timed condition. However, students in the timed condition were more accurate than participants in the untimed condition when time was matched for each math expression. However, no relations were found between working memory, math anxiety, and performance or interactions by condition.

Keywords: Math anxiety, timed testing, working memory, math performance, heart rate.

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The Effects of Math Anxiety, Working Memory, and Timed Tests on Math Accuracy

Math anxiety is associated with feelings of tension, nervousness, apprehension and interferes with the ability to focus on math calculating tasks (Ramirez et al., 2018). Many people can recall a time they felt anxious during a math lesson. In fact, in the U.S alone, an estimated 25 percent of university students and 80 percent of community college students report experiencing moderate to high levels of math anxiety when engaging in math related tasks (Yeager, as cited in Chang & Beilock, 2016). Math anxiety is not just a U.S. issue but a global one. On average, over 65 counties have reported that 33 percent of 15-year-old students feel helpless when solving math expressions (Chang & Beilock, 2016). Effects of math anxiety negatively affect student motivation, standardized math test scores, and overall willingness to engage in further math related experiences (Campbell, 2005; Chang & Beilock, 2016). Furthermore, studies have begun to show that high levels of math anxiety may be correlated with poor math performance and the departure of potential STEM students from the field, especially students from marginalized groups in STEM (Daker et al., 2021).

The goal of this study is to examine the relationships between math anxiety (MA), working memory (WM) and how they interact with one another in timed and untimed testing conditions to affect math accuracy as a measure of student performance. Participants in this study were college STEM students and/or humanities and arts majors attending a private STEM research institution in the northeastern region of the United States.

Working Memory

Working memory (WM) is a cognitive mechanism responsible for short-term memory control, regulation, and retention of limited information (Mattarella-Micke et al., 2011). WM is used to actively retain or suppress information while performing a task, such as carrying out operations and performing multistep equations in math. Additionally, WM reflects a person's ability to actively give attention and mentally control items, and is indirectly involved in memory processing (Engle, 2002). Research has also shown that WM functions as a mental workspace for handling task-related information when solving complex arithmetic (Starling-Alves et al., 2021).

Math Anxiety

Math anxiety (MA) is often defined as a “feeling of tension, apprehension, or fear that interferes with math performance” (Ashcraft, 2002, p.181) and has been known to disrupt cognitive processing by utilizing more working memory resources (Ashcraft & Krause, 2007; Suárez-Pellicioni et al., 2016). Math anxiety was previously believed to appear when children begin learning complex math, such as algebra; however, research is beginning to discover that math anxiety appears at an early age and not just in adults and older adolescents (Chang & Beilock, 2016; Sokolowski & Ansari, 2007). Children as young as six years old can self-report feelings of math anxiety, and children as early as first and second grade also report feeling nervous while in various math-related conditions (Sokolowski & Ansari, 2007). While math anxiety appears at an early age, the effects can also be observed many years later. Understanding what conditions, contexts, and factors contribute to math anxiety is vital for future research aiming to decrease math anxiety.

Working Memory & Math Anxiety

According to Ashcraft, working memory resources are depleted whenever anxiety is aroused (Ashcraft & Krause, 2007). When students experience math anxiety their attention becomes occupied with doubts and worries about their math abilities (Ashcraft & Krause, 2007). These negative thoughts take away WM resources that could be used to solve the math problem at hand. Research has also gone on to find that children with higher levels of working memory capacities are more likely to have a negative relationship between math anxiety and math achievement (Sokolowski & Ansari, 2007). Furthermore, functional magnetic resonance imaging (fMRI) studies have found that math anxiety is associated with reduced activity in the participant's dorsolateral prefrontal cortex, the region of the brain associated with working memory functions (Young et al., 2012). fMRI studies have also found that math anxiety is also associated with increased activity in participant's right amygdala and bilateral dorsal posterior insula, the brain regions responsible for processing negative emotions and pain (Lyons & Beilock, 2012; Young et al., 2012). Today, we understand that there is a relationship between math anxiety and working memory; however, research lacks exploration into how these factors affect math performance in timed and untimed conditions. If we are to understand how math anxiety affects students in school environments we must apply and compare these findings in timed and untimed conditions.

Math Anxiety and Math Performance

Overall, math anxiety and performance are often found to be negatively correlated. As math anxiety increases, student performance tends to decrease. According to Ashcraft and Krause (2007), math anxiety negatively correlated with math achievement (r = .31), high school grades (r = .30), math enjoyment (r = .75), motivation (r = .64), and high school math class enrollment (r = 0.31). Based on these findings, Ashcraft concluded that highly math anxious individuals received poorer math grades, show lack of interest/motivation in taking additional (elective) math courses, and learn math less than students with low math anxiety.

Timed Tests

In 1926, the Scholastic Aptitude Test (SAT) was adopted by the College board. The SAT back in 1926 lasted 90 minutes and included 350 problems relating to vocabulary and basic math. Multiple choice testing became popular in the 1930s. In 2001, the No Child Left Behind Grant was passed by congress, requiring students to take standardized tests on an annual basis. In 2015, the Every Child Succeeds Act was passed, decreasing standardized testing to only from third to 8th grade and one in high school. Since 2001, Students have been taking standardized timed testing from third to highschool in addition to SAT and Advanced Placement subject tests to enter college (Association, 2020). Timed testing has been a regularity in the U.S education system for many years now. In fact, according to Boaler, (2014) timed testing has been a regalar part of the instructional process for many school districts across the country, some even starting in fifth grade. Additionally, some teachers report giving students timed tests to improve their math test-taking skills and become faster problem solvers (Boaler, 2014). Educational literature in cognitive psychology states that it probably makes students worse. According to Skagerlund et al (2019), Starling-Alves (2021) and Ashcraft and Moore (2009) timed testing decreased student performance. The mixed viewpoints between education practitioners and researchers lend me to wonder the following questions; (1) do students perform better in timed testing conditions in comparison to untimed testing conditions?, (2) do timed tests hinder math performance?, (3) do higher levels of math anxiety lead to worse performance in situations of time tests?, and (4) how does working memory capacity and math anxiety interact with each other in timed versus untimed conditions?

The Current Study (RQ and what are the new approaches)

Previously published literature has investigated how math anxiety and working memory affects math performance/accuracy. However, not much literature can be found on how working memory and math anxiety affects math accuracy within timed or untimed conditions. The purpose of this MQP study is to examine if there are differences in math accuracy between participants engaging in math tasks in timed or untimed testing conditions. For my MQP, I conducted a research study where students were randomly assigned to a timed or untimed condition and were asked to solve math problems quickly and accurately.

The current study investigates if timed tests hinder student math accuracy on assessments depending on interactions between math anxiety and working memory. Several *t*-tests and regression models were conducted to examine the relations between math anxiety, working memory, and condition (timed vs. untimed tests). I additionally examined gender as some research shows differences in math anxiety when it comes to gender, but this likely is due to male students underreporting anxiety (Ramirez et al., 2018). I hypothesize that students with low levels of math anxiety will perform better in untimed and timed conditions than students with high levels of math anxiety. Additionally, I expect that students with high math anxiety will perform lower in timed conditions than untimed conditions. I also predict that students in the untimed condition will perform better than those in the timed condition overall and when matched for time allowed per problem.

This study tests the following research questions and hypotheses:

RQ1. Is there a difference in math accuracy between timed and untimed testing conditions?

Hypothesis: Students in timed testing conditions will perform worse than those in untimed conditions.

RQ2. Is there a difference in math accuracy between timed and untimed testing conditions when matching for time (i.e., when only answers from both conditions were considered if answered under the time limit the timed condition had)?

Hypothesis: Students in the untimed testing conditions will perform better than those in untimed conditions.

RQ3. Do math anxiety, working memory, gender, and condition relate to math accuracy (in both matched or unmatched conditions)?

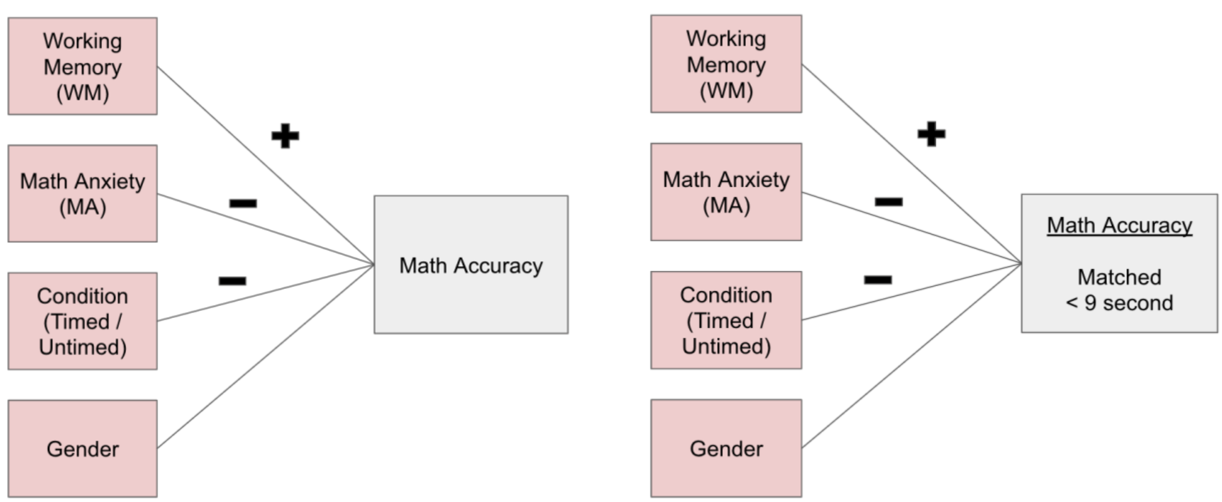
Hypothesis 1: Higher math anxiety will be associated with lower math performance in both matched and unmatched time conditions.

Hypothesis 2: Higher working memory will be associated with higher math performance in both matched and unmatched time conditions.

Hypothesis 3: Students in the timed condition will perform worse than students in the untimed condition in both matched and unmatched time conditions.

Hypothesis 4: There will be no difference between females and nonfemales in math performance, controlling for working memory and math anxiety for matched and unmatched time conditions.

Figure 1 . *Conceptual Models on Math Accuracy for Time and Untimed Testing Conditions*



Note. Conceptual Models and Hypothesized Relations between math anxiety, working memory, gender, and condition on math accuracy for both unmatched (left) and matched time (right).

RQ4. Does math anxiety, working memory, gender, or condition interact to predict math accuracy (in both matched or unmatched conditions)? More specifically, does math performance vary with higher or lower levels of math anxiety or working memory? In addition, do conditions interact with higher or lower levels of math anxiety or working memory? Lastly, do these relations differ by gender?

Methods

Participants

A total of 40 participants (27.5% males, 65% females, and 0.075% nonbinary) ages 18 to 22 were recruited to partake in this study. Participants were undergraduate university students recruited from a private higher education institution in the northeast U.S. Participants received experimental credit in a psychology class. All participants gave informed consent prior to beginning the study, and no participants were excluded from this study after data collection.

Procedure

This study followed a between-participant design and participants were run in small groups (1- 4 students at a time) for the experiment. Participants first were instructed to sit in front of a computer. Before starting the experiment participants were randomized into two conditions: timed and untimed. Regardless of conditions, all participants completed the abbreviated math anxiety scale (Hopko et al., 2003) survey with additional questions to measure their math identity, how much they valued and utilized math in their daily lives, and prior math experiences and performance in middle and high school. They were then asked to engage in the Corsi Block Tapping Task (forward) (Corsi, 1972; Kessels et al., 2000) to measure their working memory by having them recall and press a sequence of squares that flash on and off on the screen in the order they were presented in. Next, they were also informed that they would be asked to mentally simplify forty seven math expressions before filling out a brief questionnaire and then debriefing. Participants began the math fluency task which consisted of 47 math problems and asked participants to simplify cognitively demanding math expressions (e.g $10 + (1 + 2)^3$, $(10 + 6/2 - 1)$, and 0.4^3) that involve multiplication, division, addition, subtraction, and exponents (See Table 1 for sample problems). All participants were given a trial phase of five math expressions to become familiar with the task before completing the task. Participants were all shown the same math expressions regardless of study condition.

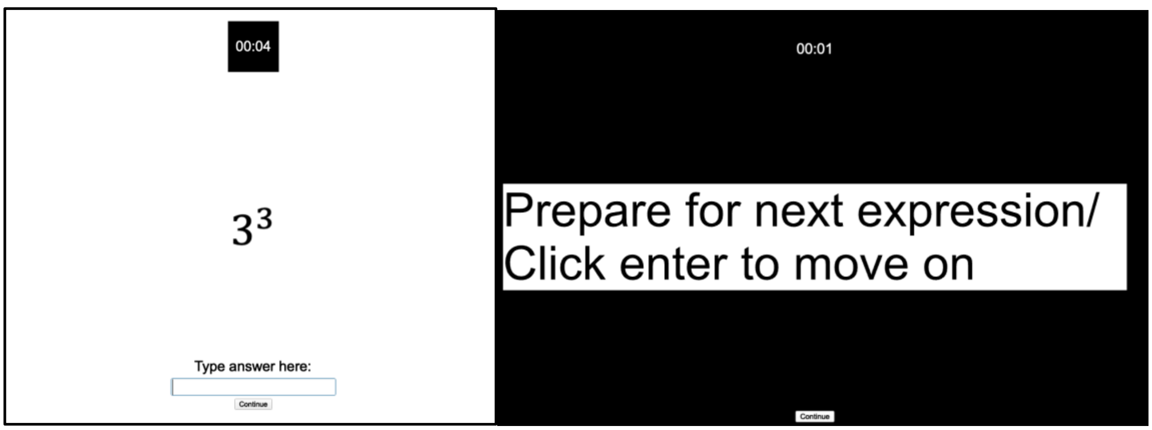
Table 1. *Sample Math Expression by Type*

Exponents	Fractions	Order of Operations
4^2	$\frac{5}{6} \div \frac{11}{9}$	$(1 - 10 \cdot 9) \cdot 3$
$(\frac{2}{3})^2$	$\frac{7}{2} \cdot \frac{6}{12}$	$\frac{10 + 6}{2 - 1}$
0.4^3	$\frac{1}{3} \div \frac{3}{2}$	$10 + (1 + 2)^2$

Note. This table shows the different kinds of problems participants responded to. Additional problems were asked during the math task in a similar format using different values.

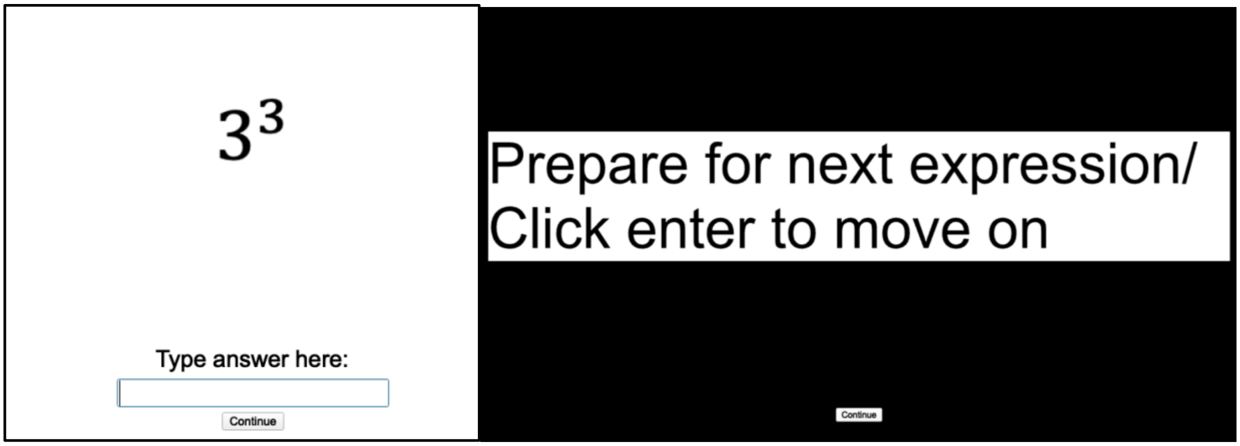
Participants in the timed condition were given 9 seconds to simplify each math expression and type their response into a text box. Participants in the timed condition also had a nine-second countdown timer above the math expression while completing the task. Participants were then forwarded to a three-second pause screen to prepare for the next math expression. Participants were then forwarded to the next math expression once the pause screen exceeded three seconds. Participants were allowed to proceed sooner on each screen but they were not permitted to spend more than the allotted time on any given screen.

Figure 2. *Timed Condition for Math Task*



Note. Participants in the timed condition had 9 seconds or less to simplify math expressions and type their answer into the text box. Responses written in the text box were automatically submitted when the timer expired. Participants had three seconds in between math expressions. Participants were asked to solve expressions as accurately and quickly as they can while having a time restriction.

Figure 3 . *Untimed Condition for Math Task*



Note. Participants in the untimed condition had unlimited time to simplify math expressions and type their answer into the text box. Responses written in the text box were submitted when the participant clicked "continue" under the text box. Participants had unlimited time in between math expressions. Participants were asked to solve expression as accurately and quickly as they can despite not having a time limit

Participants in the untimed condition were directed to simplify each expression as accurately and quickly as they could. While the problems in the 2 conditions were identical, contrary to participants in the timed condition, those in the untimed condition were not shown a countdown timer on any screen. Participants were allowed to take as much time as they wanted while simplifying math expressions and when preparing for the next expression, but were instructed to solve the problems as quickly as possible.

After completing the math task, participants answered questions asking how they generally felt about the math task and selected emotions they experienced while simplifying expressions. Before finishing, all participants completed a demographic questionnaire before being debriefed. The demographic questionnaire asked questions regarding their age, gender, college major, race, ethnicity, highest level of education, years in college, parental income, and U.S. regional origin.

Measures

Accuracy and Performance- Unmatched Time.

For an unmatched time math accuracy score, participants' performance scores were calculated based on how accurately they simplified each math expression, which resulted in a score of 1 if they provided the correct solution and 0 if they did not. These scores were summed across the 47 problems to create a math accuracy score operationalized as percent correct. Samples of math fluency tasks expressions can be seen in Table 1.

Accuracy and Performance- Matched Time

Participants' matched time accuracy score was identical to the unmatched time, except student scores in the untimed conditions were recalculated to only be scored if they submitted a correct answer in 9 seconds or under. If the time was greater than 9 seconds in the untimed condition, each problem's accuracy score was recorded as 0, regardless of whether they got the problem correct with more extended time. This helped me evaluate how the pressure of a timed exam, controlling for time, may have influenced students' performance.

Math Anxiety

Participants' trait math anxiety was measured using the Abbreviated Math Anxiety Scale (AMAS) survey (Hopko et al., 2003). AMAS is a nine question survey asking participants to answer five-point Likert scale questions ranging from "low anxiety" to "high anxiety", that were assigned point values between one and five to measure math anxiety. AMAS scores are calculated by summing up each question's responses to obtain the total score, and then dividing by 5 to obtain a participant's average math anxiety level. The minimum score a participant can score on the AMAS is 1. This score would be achieved by selecting “low anxiety” on all of the AMAS questions. The maximum score a participant can score is 5. This score would be achieved by selecting high anxiety on all of the AMAS prompts. Having an average score of one is interpreted as the participants having low math anxiety. Having an average score of 5 means a person has high math anxiety. Questions included in the AMAS can be seen in Figure 4.

Figure 4. *Abbreviated Math Anxiety Scale (AMAS) Questionnaire Assessment with Score Scale*

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

1. Having to use the tables in the back of a math book?
2. Thinking about an upcoming math test 1 day before.
3. Watching a teacher work an algebraic equation on the board.
4. Taking an examination in a math course?
5. Being given a homework assignment of many difficult problems that is due at the next class meeting?
6. Listening to a lecture in math class?
7. Listening to another student explain a math formula.
8. Being given a “pop” quiz in math class?
9. Starting a new chapter in a math book?

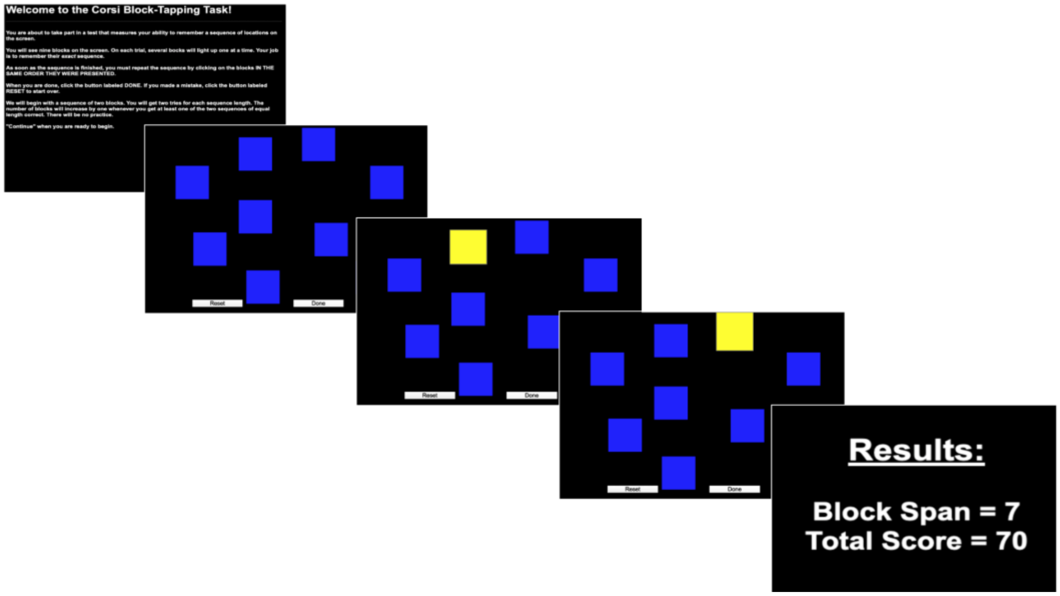
Note. The AMAS Likert scoring scale is located at the top of the figure. Questions asked on the AMAS are numbered one through nine.

Working Memory

The Corsi Block Tapping Task (CBTT) was used to assess working memory, and involves presenting blocks on a screen to a participant that flash in a certain order, requiring participants to remember the exact sequence and then repeat it back. This working memory task was chosen because it better assesses participants' visuospatial sketch pad, which has been linked to mathematics achievement in fifth through ninth grade (Li & Geary, 2017). The Corsi Block Tapping Task was also used because it does not rely on English having to be a participant's first language. A person whose first language is not English should be able to complete the task with minimal to no delayed reactions due to language. Furthermore, results from the CBTT are calculated based on the number of sequences reproduced correctly divided by the total number of sequences to be learned.

These tasks inform researchers what a participant's working memory capacity is. As shown in Figure 5, participants receive a block spam score and a total score at the end of the task. Block score is the maximum number of blocks recalled. The total score represents a participant's overall performance and takes into account the participant's “block span” and the number of errors they made while recalling any block sequence.

Figure 5. *An abbreviated example of what the CBTT looks like to the participant*



Note. The first block displays the first screen participants read before beginning the Corsi Block Tapping Task (CBTT). Blocks two through four represent what the task would look like to participants recalling a three-block span. The last block shows the result screen participants would see after completing the CBTT.

Approach to Analysis

Means, standard deviations, and correlations were calculated for each variable of interest. Next, a series of *t*-tests were conducted to examine differences in means between timed and untimed conditions. Third, regression analyses were conducted to test the relations between math anxiety, working memory, and condition on math accuracy in both matched and unmatched time conditions. Model 1 predicted overall accuracy and model 2 predicted accuracy when matched for time (by only accounting for answers that were correct at or before 9 seconds for both conditions during the math task). In model 3, we tested the interactions between math anxiety, working memory, and conditions on math accuracy.

Results

The means, standard deviations, and correlations are presented below in Table 2. Correlations show that female students reported higher math anxiety ($r = 0.44$) but showed no statistically significant differences in math accuracy. Surprisingly, math anxiety and working memory were not correlated with one another, nor math accuracy for either matched or unmatched time.

Table 2. *Variable Means, STDs, and Correlations*

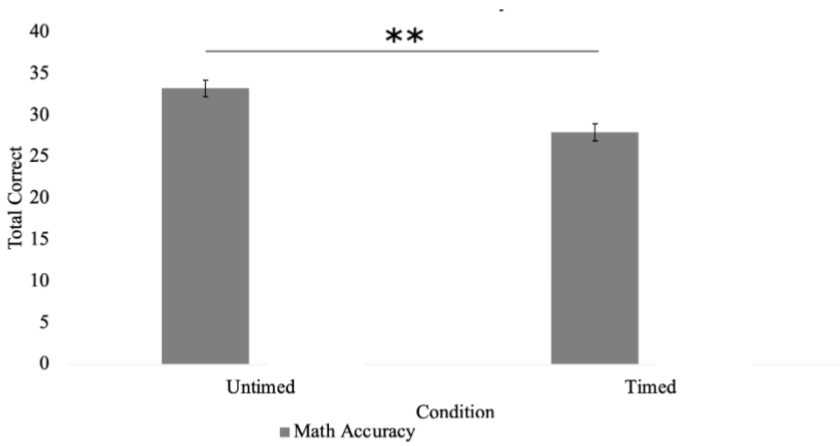
Variable	*M*	*SD*	1	2	3	4
1. Math Anxiety	2.86	0.87				
2. Working Memory	68.85	22.13	-.22 [-.49, .10]			
3. Female	0.65	0.48	.44** [.14, .66]	-.04 [-.34, .28]		
4. Math Accuracy	30.73	5.63	.00 [-.31, .31]	.11 [-.21, .41]	-.08 [-.38, .23]	
5. Math Accuracy Time	23.25	7.13	-.27 [-.54, .04]	.22 [-.10, .50]	-.03 [-.33, .29]	.14 [-.18, .44]

Note. Unmatched time is math accuracy. Matched time (9 seconds or less) is math accuracy time.

RQ1. Is there a difference in math accuracy between timed and untimed testing conditions?

Independent Sample *t*-tests indicate that the means in math accuracy between untimed and timed conditions when unmatched for time were significantly different, $t(38) = 3.30$, $p = 0.002$. Specifically, students in the untimed condition got on average 34.13 problems correct, whereas students in the timed condition got 27.67 problems correct.

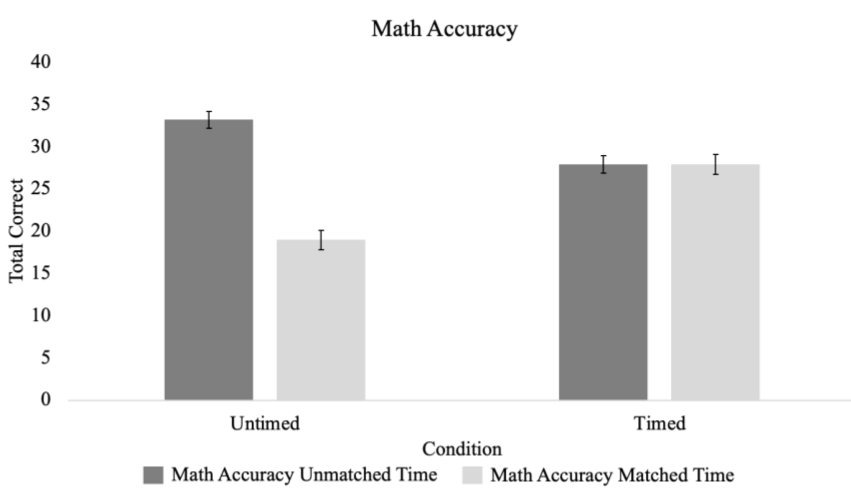
Figure 6. *Math Accuracy of Timed and Untimed Conditions*



RQ2. Is there a difference in math accuracy between timed and untimed testing conditions when matching for time (solving in 9 seconds)?

When I matched time math accuracy for 9 seconds, the opposite pattern emerged. Independent Sample *t*-tests indicate that the means in math accuracy between untimed and timed conditions were statistically significantly different from each other, $t(38) = 5.06$, $p < 0.001$. Specifically, students in the untimed condition got, on average, 20.38 problems correct, whereas students in the timed condition got 27.67 problems correct.

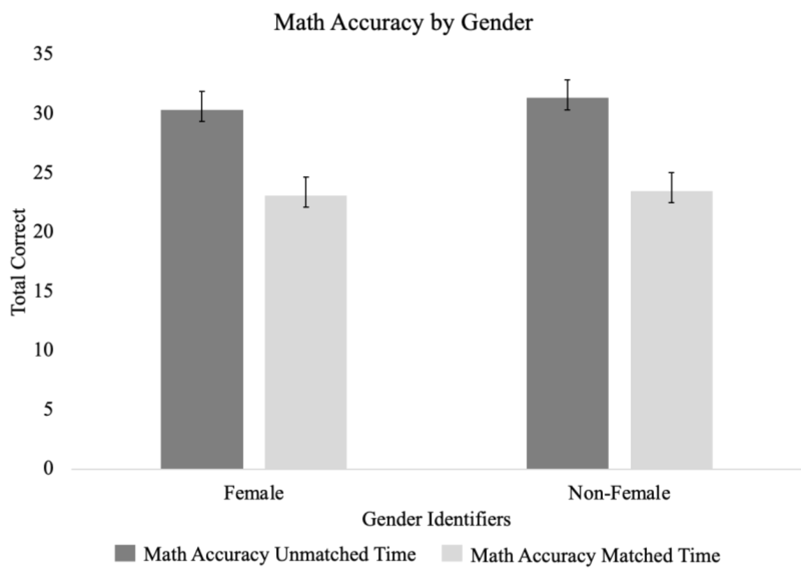
Figure 7. *Math Accuracy of Timed and Untimed Conditions for Both Matched and Unmatched Time*



RQ3. Do math anxiety, working memory, gender, and condition relate to math accuracy (in both matched or unmatched conditions)?

Results for the regression are presented in Figure 8. Results indicated that math anxiety, working memory, and gender were not significant predictors of math accuracy for matched or unmatched timed conditions. Figure 8 demonstrates no differences in mean math accuracy between female and non-females participants.

Figure 8. *Math Accuracy by Gender*



However, for both the unmatched and matched time conditions, there were significant effects of the condition (timed vs. untimed) (p's<0.001) on math accuracy. As seen in Table 3, participants assigned to the untimed condition solved on average 6.002 more correct problems than participants in the timed condition. However, the opposite effect was found when matching for time (solving problems in 9 seconds or less). Specifically, participants assigned to the untimed condition solved on average 8.388 fewer problems than participants in the timed condition, as seen in table 4.

Table 3. *Main Effects of Condition on Performance When Time is Unmatched*

Variables	*B*	*SE*	*t*	*p*
Intercept	25.082	4.290	5.846	<0.001
Corsi	0.056	0.038	1.465	0.152
AMAS avg.	-0.445	1.094	-0.407	0.686
Female	-0.013	1.890	-0.055	0.957
Condition untimed	6.002	1.693	3.544	0.001**

$R^2 = 0.2816$, F= 3.43, p = 0.018

Table 4. *Main Effects of Condition on Performance When Time is Matched*

Variables	*B*	*SE*	*t*	*p*
Intercept	29.168	4.869	5.991	<0.001
Corsi	0.020	0.043	0.466	0.644
AMAS avg.	-0.970	1.241	-0.782	0.440
Female	-0.191	2.145	-0.089	0.929
Condition untimed	-8.388	1.922	-4.365	0.001**

$R^2 = 0.424$, F = 6.430, p <.001

RQ4. Does math anxiety, working memory, gender, or condition interact to predict math accuracy (in both matched or unmatched conditions)?

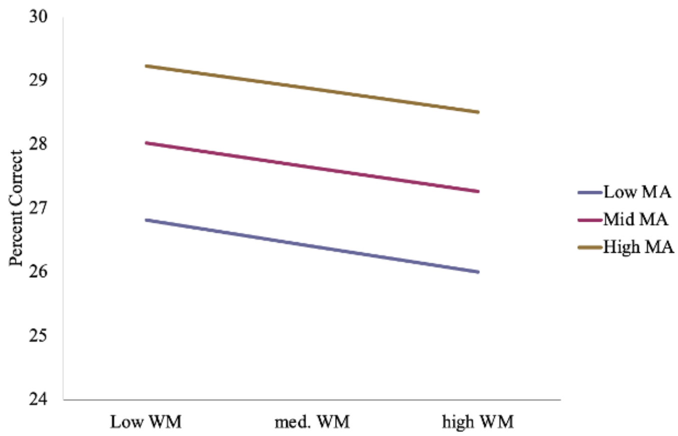
A series of 8 moderation models (4 for matched time and 4 for unmatched time) were conducted to examine the interactions between math anxiety, working memory, gender, and condition. Results indicated no statistically significant interactions among any of these combinations, all p's >0.10). For example, Table 5 displays the regression results accounting for the interaction between working memory and math anxiety in the matched condition. Additionally, Figure 9 graphs the relations between high and low levels of math anxiety and working memory in predicting performance. The slopes of the lines are nearly parallel, demonstrating that no interaction is present. No further tables or figures are presented given the lack of any interactions (all p's>0.10) for both matched and unmatched time among these 4 variables.

Table 5. *Regression Table Predicting Math Accuracy Accounting for Gender, AMAS, Corsi, Condition, and Interaction Variable Between AMAS and Corsi (When matched for time)*

Variables	*B*	*SE*	*t*	*p*
Intercept	25.082	4.290	5.846	<0.001
Gender	-0.095	1.937	2.574	0.961
AMAS avg.	-0.534	3.231	-0.049	0.870
Corsi	0.052	0.139	-0.165	0.713
Condition untimed	5.987	0.047	0.371	0.0020**
AMAS avg * Corsi	0.001	0.047	0.029	0.977

Note. The regression predictors explained 21.86% of the variance (R^2 =0.2186 , F(4,35)=3.43, p=1.816). It was found that untimed conditions performed better than the timed condition when matched for time (β = 5.987, p=0.0020. No interaction was found.

Figure 9. *Interaction of Math Anxiety and Working Memory for Unmatched Time*



Discussion

This experimental study examined the relations between working memory, math anxiety, gender, and timed testing on math accuracy. Results indicated no statistically significant relations between math anxiety, working memory, gender, and math accuracy. However, statistically significant differences in math accuracy were found for timed vs. untimed test conditions. Specifically, when unmatched for time, participants in the untimed testing condition outperformed their peers in the timed condition. Interestingly, when time was matched and I examined how many problems participants were able to solve within the first 9 seconds, students in the timed condition outperformed those in the untimed condition.

One possible explanation for this is that timed students are more likely to solve problems quickly when aware of a time constraint. Interestingly, students in both conditions were told to solve problems as accurately and quickly as possible. However, it seems as if being under time pressure makes people more accurate and faster than not giving students those constraints. This may be due to not having enough time for people to second guess or self-doubt their responses.

An additional possible explanation for this is that students in the untimed condition are more likely to second guess or doubt their math capabilities. Even when people are told to solve problems as quickly and accurately as possible with no time constraints, they will spend as much time as needed to complete the task or more. Based on past literature about working memory and math anxiety, we understand that giving attention to thoughts of self-doubt students leaves fewer working memory resources available for the task at hand. People in untimed conditions may take more time to solve math expressions compared to people in timed conditions because they utilize less working memory resources on the task and more on thoughts related to self-doubt and personal capabilities.

Part 2: Beating the clock: An exploration into whether heart rate increases for timed conditions?

People with higher levels of math anxiety show heightened autonomic nervous system responses, such as heart rate (Qu et al., 2020). Research has also shown a correlation between higher levels of math anxiety and increased heart rate (Faust, 1992; Qu et al., 2020). However, there is no research on whether heart rate correlates with math anxiety, working memory, or math accuracy when applied in timed and untimed testing conditions.

As part of this larger study, I was interested in examining whether there were observable differences in average heart rate for students assigned to each testing condition. To answer this, I collected heart rate information from a subsample of participants from the main study. This smaller exploratory study examines whether there is any evidence that heart rate increases for participants involved in timed testing conditions compared to those in the untimed condition. I predict that the average heart rate for participants in the timed condition will be higher than the untimed condition when solving math expressions.

Method

Participants

18 out of 40 college student participants from the previous behavioral study participants (11 females, a non-females, 1 unknown) were recruited to partake in a psychophysiological study. Participants in the psychophysiological study followed the same procedure as study one, with the exception of placing a Garmin Activevivo 3 watch on their rough wrist to collect heart rate data. Participants who opted to provide heart rate data followed the same procedure as participants from the first study (the only difference was the collection of heart rate data).

Procedures

At the start of the experiment, participants were instructed to sit in front of the computer and place a Garmin Vivoactive 3 watch on their right wrist and then wait five minutes to begin the study. The Garmin Vivoactive 3 watch was used to collect participants' heart rate data every five minutes throughout the experiment. Next, participants filled out the Abbreviated Math Anxiety Scale (AMAS) to determine their math anxiety levels. Then participants engaged in the Corsi Block Tapping Task to measure their working memory capacities. Once completed, participants were asked to simplify 47 math expressions. Lastly, they were asked to answer a brief demographic questionnaire before being debriefed.

Measures

All measures for this study were identical to what was described in the study above. However, we also collected heart rate data using the Garmin watch. The following measures of heart rate were recorded.

Heart Rate Data

Heart rate data is made out of four components, initial heart rate, baseline heart rate, interval timepoints, and average heart rate. Initial heart rate is a participant's first heart rate reading after placing the Garmin watch on their wrist. Baseline heart rate is a participant's first 5 minute interval heart rate reading. Interval heart rate readings were recorded from time zero to twenty minutes in five minute intervals but mainly focus on heart rate reading from ten minutes to twenty minutes.

Results

Descriptive statistics for heart rate data can be found in Table 6 and Figure 10 illustrates heart rate intervals for a given recording. To determine whether or not the visual differences in means were significantly different from each other, I conducted three independent sample *t*-tests by condition for baseline heart rate, average heart rate, and heart rate at the 10 minute mark, indicating the beginning of the math task (See Figures 11 and 12). Independent Sample *t*-tests indicate that the means in baseline heart rate, average heart rate, and heart rate at 10 minutes (at the average beginning time for the math task) between untimed and timed conditions were not significantly different from each other, all p's > 0.35.

Additional analyses were not conducted due to the small sample size of participants with heart rate data. Further work will collect additional participants to examine these relations in greater detail.

Table 6. *Raw Participant Heart Rate Data*

Condition	Participant ID	Time in Minutes					Participant Average Heart Rate
		0 Minutes (Initial)	5 Minutes (Baseline)	10 Minutes	15 Minutes	20 Minutes	
Timed	897836225	74	68	81	53	69	68.833
	118907544	126	79	87	84	81	81.200
	108518539	68	87	94	83	76	83.286
	79124071	82	82	80	72	74	75.000
	8912071	85	97	97	93	89	94.000
	277857428	100	108	109	96	110	105.750
	377857428	77	92	103	106	89	97.500
	498889974	88	79	73	69	69	73.429
Untimed	610152836	124	114	103	101	101	106.400
	913330588	61	84	90	83	79	82.300
	710152836	124	114	102	101	104	103.800
	781083552	77	75	98	86	94	87.333
	980166491	69	92	89	84	92	89.200
	864831466	80	77	78	83	74	76.800
	560578447	82	73	69	67	67	69.000
	262226595	69	105	96	99	98	97.714
	362226595	77	62	48	60	59	60.143
	112474231	81	59	61	58	69	60.167

Table 7. *Average Heart Rate by Time Interval*

Condition	0 Minutes		5 minutes		10 minutes		15 minutes		20 minutes	
	Heart Rate	*SD*	Heart Rate	*SD*	Heart Rate	*SD*	Heart Rate	*SD*	Heart Rate	*SD*
Timed	87.500	18.315	86.500	12.410	90.500	12.375	82.000	16.937	82.125	13.737
Untimed	84.400	21.869	85.500	20.118	83.400	18.763	82.200	16.047	83.700	16.028

Table 8. Means, Standard Deviations, and Correlations with Confidence Intervals

Variable	*M*	*SD*	1	2	3	4	5	6	7
1. Condition	0.56	0.51							
2. AMAS Avg	2.76	0.82	.37						
			[-.11, .72]						
3. Corsi Task	69.94	21.01	-.48*	-.26					
			[-.77, -.02]	[-.65, .23]					
4. Female	0.67	0.49	.08	.25	-.04				
			[-.40, .53]	[-.25, .64]	[-.50, .43]				
5. Unmatched	32.33	5.11	.49*	.22	-.17	.02			
			[.03, .78]	[-.28, .62]	[-.59, .32]	[-.45, .49]			
6. Matched	22.06	8.74	-.80**	-.22	.37	-.08	-.02		
			[-.92, -.53]	[-.62, .28]	[-.12, .71]	[-.53, .40]	[-.48, .45]		
7. Baseline HR	85.94	16.67	-.03	.18	-.35	.19	-.18	-.22	
			[-.49, .44]	[-.32, .59]	[-.70, .14]	[-.31, .60]	[-.60, .31]	[-.62, .28]	
8. Avg HR	83.99	14.80	-.05	.14	-.23	.05	-.21	-.22	.95**
			[-.51, .42]	[-.35, .57]	[-.63, .26]	[-.43, .51]	[-.62, .29]	[-.62, .28]	[.87, .98]

Note. M and *SD* are used to represent mean and standard deviation, respectively. Values in square brackets indicate the 95% confidence interval for each correlation. The confidence interval is a plausible range of population correlations that could have caused the sample correlation (Cumming, 2014). * indicates $p < .05$. ** indicates $p < .01$.

Figure 11. *Average Heart Rate For Each Time Interval*

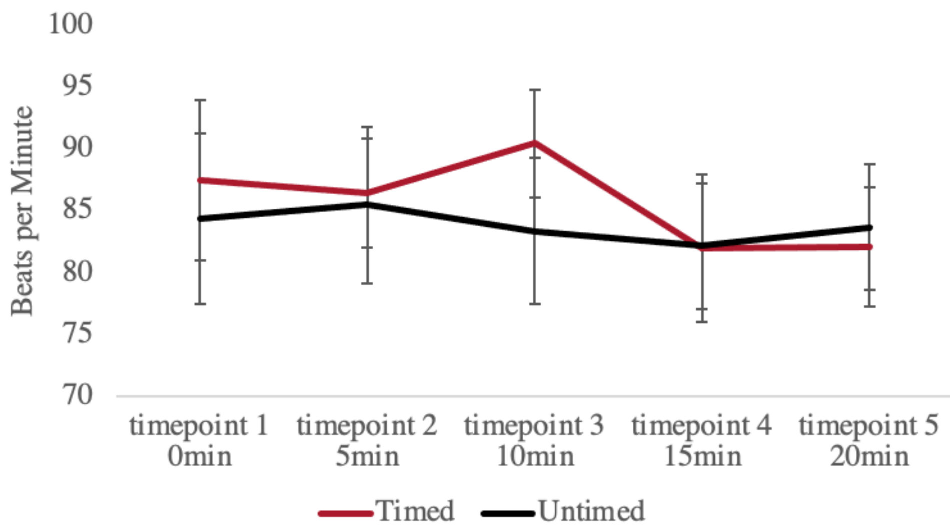
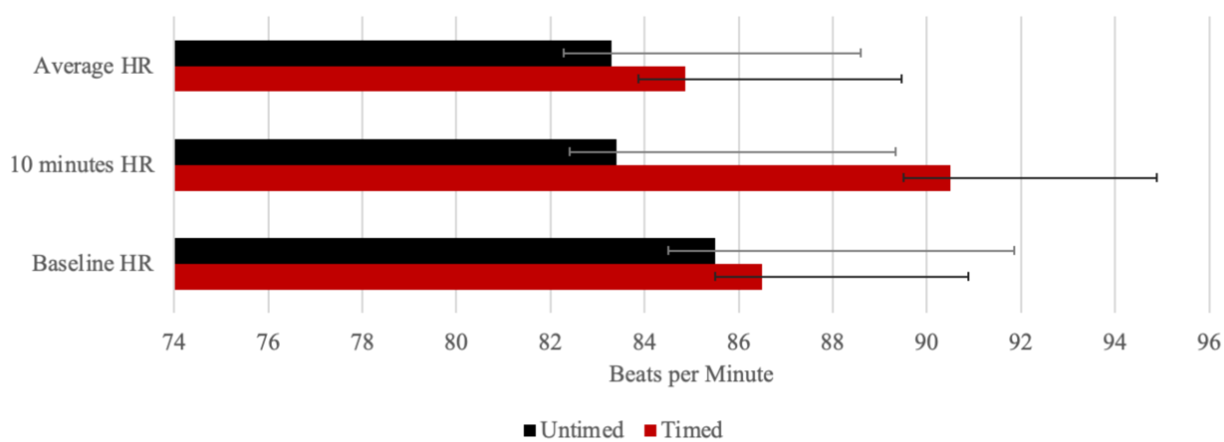


Figure 12. *Average Heart Rate, Start of Math Task Heart Rate, and Baseline Heart Rate Data*



Overall Discussion

This MQP examined how working memory, math anxiety, math accuracy, and heart rate contributed to math accuracy in timed and untimed testing conditions. To investigate these interactions a behavioral study was designed to examine how working memory and math anxiety affects math accuracy in timed and untimed testing conditions. Participants entered the lab and were randomly assigned into the timed or untimed testing condition. To further investigate how working memory, math anxiety, and testing conditions contributed to math accuracy, participants from both conditions were matched for time (taking 9 seconds or less to solve an expression correctly) in timed and untimed testing conditions.

Furthermore, results from this study show a main effect of condition on performance. Participants assigned to the untimed condition were significantly more accurate than participants assigned to the timed condition. This corroborates past research that argues that timed tests may negatively affect performance (Ashcraft and Moore; 2009; Skagerlund et al., 2019; Starling-Alves, 2021). However, when math performance was matched for time (solving expressions in 9 seconds or less), participants assigned to the timed condition were significantly more accurate and solved more problems. This study found that working memory, math anxiety, and timed testing conditions do not interact to negatively impact math performance. Interestingly enough, results show that timed testing when matched for time increased math accuracy.

An exploratory psychophysiological study also investigated how working memory, math anxiety, and heart rate affect math accuracy in timed and untimed testing conditions. As this study was exploratory and had a small sample, it provided a means to be able to explore heart rate as a potential mediator of decreased performance. Results from the psychophysiological study indicate that on average, participants assigned to the timed condition had higher heart rate averages than participants assigned to the untimed testing condition when beginning the math task; however, results were not significant and yielded large margins of errors.

Together, these approaches provide insight into how timed tests contribute to math accuracy and student emotions when solving cognitively demanding math expressions. Furthermore, this exploratory aspect of the study provides cognizance of how biomarkers relate to math anxiety, working memory, and accuracy. Results from this indicate that there are no interactions between working memory, math anxiety, math accuracy, heart rate, gender and condition, but future research is needed.

Limitations and Future Directions

This study was conducted at a STEM Institution in the northeastern region of the United States. Students from this institution likely do not have a full range of math anxiety resulting in no relations being found between math anxiety and performance like other previously published literature has found. It is also important to note that the sample size for this study was small due to the logistical constraints of the extenuating circumstances of the global pandemic and participant comfortability with attending in person lab sessions. Having a small sample size also contributes to difficulty to detect statistically significant results that may exist. This experiment was also conducted having participants solve mental arithmetic. Participants in timed conditions were tiem restricted to the problem level. Thus, future work can collect more participants, look at a more diverse student body, and look to see if patterns of results hold if students were given 561 seconds (total seconds available in the timed condition) instead of nine seconds for each problem with three second breaks in between.

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