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## Quantitative Reasoning: Individual Differences In Heart Rate and Response Latency


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**QUANTITATIVE REASONING: INDIVIDUAL DIFFERENCES IN HEART RATE AND  
RESPONSE LATENCY**

A Master's Thesis

Presented to

The Graduate College of  
Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree  
Master of Science, Experimental Psychology

By

Abigail Van Nuland

May 2019

# QUANTITATIVE REASONING: INDIVIDUAL DIFFERENCES IN HEART RATE AND RESPONSE LATENCY

Psychology

Missouri State University, May 2019

Master of Science

Abigail Van Nuland

## ABSTRACT

Math is something that all students are required to use at some point during their academic careers. Then they must use it again in the real world. Unfortunately, many students struggle with quantitative processing. In the current study, participants answered first grade level math problems in order to assess cognitive effort when solving math problem. Participants were then assigned randomly to one of two conditions; *Answer* or *Equation*. In the *Answer Condition* participants were asked to solve a series of math problems, whereby they were given a math equation and then they were asked to choose an answer. In the *Equation Condition*, participants were given the answer, and then they were asked to choose the math equation to which the answer corresponds. The participants' heart rate (HR) was recorded concurrently as well as their corresponding response latency (RL). It was hypothesized that participants in the *Equation Condition* would have greater evoked HR (acceleration) and faster RL compared to the *Answer Condition*. This hypothesis was supported. Moreover, it is predicted that the magnitude of evoked HR will be predictive of RL. It is argued the greater the evoked HR, the greater cognitive effort (encoding) the faster the RL. Although not statistically significant, the trends were in the hypothesized direction.

**KEYWORDS:** Evoked Heart Rate, Attention, Quantitative Reasoning, Match-to-Sample, Response Latency, Problem Solving

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A Master's Thesis  
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In Partial Fulfillment of the Requirements  
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In the interest of academic freedom and the principle of free speech, approval of this thesis indicates the format is acceptable and meets the academic criteria for the discipline as determined by the faculty that constitute the thesis committee. The content and views expressed in this thesis are those of the student-scholar and are not endorsed by Missouri State University, its Graduate College, or its employees.

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## INTRODUCTION

Students often complain when they are required to enroll in a course that includes a mathematical component, even though basic math is something they often use in day to day life. These courses are encountered initially when students first enter school, and never go away no matter what path in life they take. Whether it is advanced calculus, or counting change in a cash register, quantitative reasoning is something that all students are forced to become comfortable with. Even though students are exposed to this form of information at an early age, there are some that never quite grasp an understanding of it.

### **Quantitative Processing**

Successful problem solvers, and unsuccessful problem solvers have been found to exhibit different methods in the way they solve quantitative problems. It has been shown that unsuccessful problem solvers only base their solution to a quantitative problem on numbers, while successful problem solvers construct a model (Hegarty, Mayer, & Monk, 1995). While this study was done using word problems, it seems that it is safe to generalize the results to basic algebra due to the fact that it involves quantitative intelligence. Essentially, this means that unsuccessful solvers are focused completely on the numbers and leave the context of the problem out of their solution. Whereas successful problem solvers put it into context and create a model with the information provided: they realize that all mathematical concepts are related. It was not clear as to whether this was a conscious, or unconscious process. It seems that there are individual differences in the solving of math problems. Interestingly, unsuccessful problem solvers did not change their strategy as the trials progressed. Even when faced with failure, they



did not change the way they approached the problem. They showed the same pattern of errors through the study (Hegarty, Mayer, & Monk, 1995). It is fair to question whether this is because they are not aware of any other problem-solving strategies. Students are often punished when they do not solve problems in the same manner as their teacher, even if they arrive at the same correct answer. It is obvious that many students struggle in math courses, but is this because we have failed to teach them more than one problem solving method?

There is evidence that this may be true. One reason that Japanese students often outperform American students in mathematics is because American students are often taught short cuts to solve math problems with emphasis on getting the correct answer, whereas Japanese schools emphasize understanding how the answer is achieved (Stevenson & Stigler, 1992). This emphasis on understanding how an answer is achieved, versus just knowing what the correct answer is, is theorized to be an important part of learning math. While we can see that teaching students how to understand what they are doing in math improves their ability to solve problems, this is not a cure-all solution for students who struggle in math.

It has been shown that math elicits emotional and behavioral reactions from some individuals. For example, math can evoke an emotional, panicked response from students, and learners of all demographics (Tobias, 1978). These emotional responses are defined typically as math anxiety. Math anxiety has been shown in every demographic and can have negative impacts on education.

Some researchers argue that self-reported math anxiety is just another symptom of overall trait anxiety. Dreger and Aiken (1957) hypothesized that trait anxiety and math anxiety were conceptually different ailments, but this was not corroborated until Hembree (1990) found that there a moderate correlation ( $r = .38$ ) between trait anxiety and math anxiety. While individuals

who self-report high levels of math anxiety do tend to score higher on traditional measures of trait anxiety, these two types of anxiety are clearly separate entities. Consequently, researchers have suggested that math anxiety, and test anxiety are interchangeable. Similarly, it was found that the relationship between math anxiety and test anxiety share a coefficient of determination ( $R^2$ ) of .37 (Dew, Galassi and Galassi, 1983). This means that only 37% of variance in one of these variables can be accounted for by the other variable. Researchers have since concluded that it is unlikely that math anxiety is completely restricted to testing situations, and that these two types of anxiety are in fact different (Hembree, 1990). While math anxiety does have relationships with both trait anxiety, and test anxiety, it has been shown to be its own type of anxiety.

Math anxiety has been shown to have detrimental effects on the education of individuals who must live with it. It has been found that there is a positive relationship between self-reported math anxiety and the time it takes to respond to a math problem, which indicates reduced processing efficiency (Hunt et al., 2015). This is quantitative evidence that math anxiety, and inefficient processing both contribute to inappropriate mapping and modeling of numerical problems. This is supported as well by the fact that an increase in math anxiety is reflected in an increase in fixations and dwell time when using eye tracking technology (Hunt et al., 2015). Eye tracking has become a common way to study specific forms of anxiety. When spider-anxious individuals are presented with a picture of an arachnoid, participants tend immediately and fixate on the creature, then will avoid attending to the picture for the rest of the trial (Rinck & Becker, 2006). Individuals who did not report spider-anxious tendencies did not show these same patterns of fixations. These are the same patterns we see with individuals with math anxiety.

They immediately attend, and fixate to the numbers, but then avoid them for the rest of the trial (Hunt et al., 2015).

In academic settings, this could lead to slow completion of tests and homework for a math class, and moreover, in natural settings math issues could affect creating a budget and taking advantage of store discounts. Math anxiety prevents consumers from correctly calculating discount prices and going for deals that are not as beneficial to them (Suri, Monroe, & Koe, 2013). For example, when given the choice between an absolute discount (\$10 off a \$50 purchase) and a relative discount (20% off a \$50 purchase), they are more likely to pick the item that is only \$10 (Suri et al., 2013). The same study found that this effect is still there even when the participant is offered a greater relative discount (\$10 off a \$50 purchase, and 25% off a \$50 purchase) (Suri et al., 2013). Over time, these deficits can build up and have real impact on these individuals' lives. If the student misses out on good test scores on every math test they take, their GPA will decrease, and they may not have the opportunities for higher education than their non-math anxious classmates. All students are consumers, or will someday become consumers, and if they are not taking advantage of as many discounts as their non-math anxious peers, they may pay for it financially as well.

As noted above, math anxiety can affect individuals emotionally and behaviorally, however such findings have led researchers to questions whether math anxiety has physiological symptoms. When math-anxious individuals solved difficult math problems, the evoked HR increase across trials, but not for verbal problems of the similar difficulty (Faust, 1992). The comparison between the verbal problems, and the math problems demonstrated that the evoked HR response could be a function of math anxiety. Students who did not report symptoms of math anxiety showed the same pattern of HR acceleration between the verbal and math problems

(Faust, 1992). This is evidence that teaching students the logic of solving math problems will increase their ability to solve them, but that some students may have a physiological and behavioral reaction when it comes to learning math. The development of math anxiety can start at an early age, and the effect can be experienced throughout life. The magnitude of gray matter found in the brain at age 8, has been found to predict longitudinal gains in quantitative ability, but not in reading abilities (Evans et al., 2015). Intrinsic connectivity analysis revealed that the strength of functional coupling among these regions also predicted gains in quantitative abilities. The children who had low levels of gray matter had more reports of math anxiety later in life (Evans et al., 2015). Once again, this is evidence that individual differences in quantitative processing may be more than just a lack of motivation or effort, but instead is linked to a physiological deficiency.

Obviously, there are individual differences in the ability to solve math problems, with or without the presence of math anxiety. It is the contention of the author that individual differences in HR could be a reliable assessment of cognitive effort when solving math problems. The following section is a brief review of link between attention and HR in an effort to support the use of HR as an indicator of cognitive activity when solving math problems.

### **Attention and HR**

Attention is a process that takes place outside of our conscious awareness. According to Gibson, attention refers to perceiving in relation to a task or goal which is externally or internally motivated (Gibson & Rader, 1979). In Gibson's theory of perception, motivation is an important component of attention. Perceiving an object or event is not enough to result in learning. One has to be motivated and learn to attend selectively to the stimulus event. The person may orient their

attention to a puppy playing on the grass, hence perceive this stimulus event; but the person who selective attends to aspects of the puppy's play, and decides to go and pet the puppy is to it has tailored their behavior to this stimulus event; therefore, joining perception, attention and the individual's subsequent behavior. According to Gibson, for someone to be described as attending to a stimulus, they must be motivated to perform a task or achieve something (Gibson & Rader, 1979). Gibson emphasizes that motivation is a large part of attention. This may not have to be an action. For example, I may be motivated to look at the puppy playing in the grass because I see something moving and my superior colliculus is stimulated. Unlike perception, issues with attention are usually due to a behavioral or psychological deficiency (Gibson & Rader, 1979). Learning through attention is generally known as the perceptual pickup of information that has optimal utility for the task at hand, resulting in perception that is efficient and economical for performance (Gibson & Rader, 1979).

Jennings (1986) hypothesized that the act of attending may serve to allocate energy to support processing of information by changing cardiac function. Essentially, Jennings believed that HR could be an indicator of other processes, such as attention. The physiological measure of HR as an indicator of other psychological functions is not a new concept but is not a concept that has been explored fully. Processes outside our conscious attention are very difficult to measure, but not impossible with the physiological measures and technology we have today. Attention can be selective and/or an unconscious process. Regardless, attention that can be very difficult to measure directly. It has been suggested that physiological measures provide information about attention (Jennings, 1986). Jennings suggests an organizational framework to determine whether a process actually measures attention. First, is an autonomic change an indicator of attention? Next, does autonomic change facilitate attention? Last, does autonomic change regulate

attention? If these three questions can be answered positively, we can be confident that attention is being measured, according to Jennings.

HR itself is measured traditionally using “beats per minute.” Simply put, HR is the number of times your heart beats per minute, otherwise known as your pulse. Resting HR is typically between 60 – 100 beats per minute. Athletes tend to have very low resting HRs, while overweight people tend to have very high resting HRs. In research, HR tends to be monitored by an electrocardiograph. An electrocardiograph measures electrical impulse generated by the heart, which cause the heart to contract and pump blood through the body (Prajent, 2011). There are many ways to measure HR, but an electrocardiograph is by far the most accurate. The electrical impulses are generated by the depolarization and repolarization of the heart. Repolarization is the relaxation of the heart muscle, while depolarization is when the heart muscle clenches. An electrocardiograph uses electrical nodes on the ankles and wrist to detect HR. Employing HR as a measure of attention provides a means by which researchers can observe small, unconscious changes in the human psyche with accuracy. In the past, this science has relied on self-report measures, and other less accurate measures to define and study concepts. It is the contention of this author that physiological changes in HR can be used to assess individual differences in cognitive effort. However, there are several factors that influence HR. For example, body temperature, physical activity, medication, and emotions can all effect HR (Stauss, 2003). Hence researchers should make note of these confounding factors when assessing changes in HR. Such changes in HR could be something other than the treatment effect, resulting in a Type 1 error.

**Individual Differences in HR.** While Jennings’s (1986) approach to HR was theoretical, HR has been shown to be an indicator of attention in several populations. Richards and Casey (1991) found that during sustained attention HR decelerated below baseline (pre-stimulus

presentation) and when attention was terminated, HR returned to the baseline level. Although this study was conducted on infants, it is often generalized to adult samples. It is particularly interesting because, we see the relationship between HR and attention, but it also introduced a method for investigating visual information processing during infancy.

HR variability has also been found on several different cognitive tasks. One study found that tasks such as solving math problems and solving anagrams increased HR while excess noise and watching flashing lights decreased HR (Lacey, Keagan, Lacey & Moss, 1963). First, this is interesting because we see HR variability in different situations, but the situations where HR decreased involved little to no cognitive effort. Watching lights flash requires almost no cognitive effort, whereas the participants much cognitively engage to accurately solve the math problems. This is support once again for Jennings's theoretical framework that HR and sustained attention have a relationship, because here we see variability based on the task. This study also generalized that cardiac acceleration is related directly to rejection of environmental input (Lacey et al., 1963). Essentially, the researchers argued that HR variability is associated with changes in mental effort. This is the first important step in supporting Jennings's theoretical framework. This evidence provides support that HR has a place in psychological cognitive research, giving unconscious thoughts and processes to be studied with accuracy. Later, it was found that HR deceleration facilitates attention in both the intake and output of information processing (Lacey & Lacey, 1974). Essentially, HR slows down as our body interprets information, and engages in a cognitive task.

HR has also been shown to represent other unconscious processes. For example, Quintana et al. (2012) found that HR variability as a marker for the ability to respond to social and emotional cues. That is the greater HR variability the better one is at recognizing emotional

cues. This is, important because there is increasing evidence that cognitive processes and HR are associated, but it remains unclear the interaction between problem complexity, emotions, and HR. Emotions are a complex cognitive process and it can be difficult to assess on how others are feeling or have trouble “reading a room.” Using HR as an individual difference measure of attention and/or emotion could improve our ability to identify individuals with these cognitive or emotional issues. Researchers have been able to demonstrate individual differences in HR on several tasks, but little work has been done when relating attention, heart rate, and unconscious thought.

**Attention and Unconscious Thought.** Attention is an often studied topic in the field of psychology. For example, researchers have explored attention bias in children using HR as their measure of attention. They found that vicarious learning led to lasting changes (Reynolds, Field, & Askew, 2014). As well, HR, although not statistically significant (small sample size), was correlated positively with avoidance behavior (slower response times in fear induced situations). While this study is not focusing on longitudinal learning, this is evidence that learning, and attention can be measured using HR. And too, the direction and magnitude of HR change has been found to be a function of cognitive demands. Hershman and Gibson (1979) found that, depending upon task demands and environmental stimulation, differential direction of evoked HR was observed. HR acceleration was observed during mental elaboration, particularly on the easy tasks, and HR deceleration when external stimulation (e.g., white noise) was presented during completing a cognitive task. This again, lends support for the Lacey and Lacey (1974) environmental intake-rejection hypothesis, and moreover, demonstrated that that physiological measures such as HR can be used a measure of attention.



Both the above studies show that HR and attention are correlated, however, the magnitude of this relationship and the theoretical interpretation is still an empirical question. Hershman and Gibson (1979) had a small sample, Reynolds et al. (2014) had a sample of children, which one could argue that this limits the generalization of their respective findings. Although Reynolds et al. (2014) found that attentional bias and fear related learning was related to anxiety and subsequent changes in HR, the magnitude of this relationship is questionable given that the measures of anxiety were based upon the children's self-reports via anxiety and fear belief questionnaires.

### **The Aims of the Current Study**

The aim of the current study is to investigate the relationship between attention, as assessed via HR, while solving simple math problems. Participants were given five first grade level math problems. Participants were given either a math equation, and asked to select the correct answer, or given the answer, and asked to select the correct equation. In the condition that is referred to as *Equation*, the participants were given a math problem and asked to select an answer. In the condition that will be referred to as *Answer*, the participants were given the answer to a math problem and then asked to select the problem it belongs to.

It was predicted that there will be individual differences in evoked HR as function of condition. It is hypothesized that the participants in the *Equation Condition* will display greater HR acceleration during the presentation of the question compared to participants in the *Answer Condition*. Also, it was hypothesized that participants in the *Answer Condition* will have slower RL than participants in the *Equation Condition*, meaning that it will take them longer to solve the math problem. The differences in HR are argued to represent individual differences in cognitive

processing effort. Given such individual differences, a secondary hypothesis was that HR, within conditions, would be correlated with RL. That is that the greater the evoked HR (acceleration), which we argue indicates cognitive effort, the faster the participant's RL. It is assumed that the magnitude of HR acceleration would indicate more in-depth processing of the math equation, hence a more readiness to respond.

## METHOD

### Participants

Given that HR was the primary dependent variable, the *a priori* power analysis was employed using an estimated effect size (Cohen's  $f = .35$ ) based upon to the literature review and recent MSU theses (e.g., Eschman, 2013; Ham, 2015) assessing evoked HR on a match-to-sample task. A literature review of HR differences across a variety of studies revealed the measure of eta squared between two studies was 0.22, 95% CI (0.07, 0.43). The average Cohen's  $d$  measure for these studies was 1.00, 95% CI (0.42, 1.58). And converting the Cohen's of 1.00 to an eta squared, results an eta squared of .20, which is in concordance with observed effect sizes of evoked HR found by Eschman (2013) and Ham (2015). Thereby, using GPower, employing a power of .80, an alpha of .05 for the primary statistical analysis (a mixed ANOVA (1 between X 5 within) it was found that a sample size of 21 participants per condition would be appropriate.

The participants in this study ( $N = 37$ ) were recruited from an introductory psychology course at a midsized midwestern university. The participants were given course credit for their participation. The sample of participants was compiled of females ( $n = 20$ ) and males ( $n = 17$ ). The mean age of participants was 19.73 ( $SD = 2.88$ ) years. The maximum age of participants was 32 years, and a minimum of 18 years.

### Materials

A Bio-Pac electrocardiograph was used to measure HR via a BIOPAC System MP30 amplifier. Disposable leads (Medicotest Blue Sensor, N-00-S) were placed on both the

participant's ankles and on their left wrist. The BIOPAC System was interfaced with the laboratory computer (Dell OPTIPLEX GX-820) which recorded and stored all the HR data.

In order to ensure the math problems were equated, 38 participants were required to answer a series of simple math problems. Five math problems were selected randomly from a 40 question quiz given to this sample upper classman undergraduate psychology students.

Demographic information was not collected and is not expected to be pertinent to calibrating the stimulus. All 40 quiz questions were written to be at a first-grade level of difficulty. The math problems that were found to have the same percentage correct (100%), were assigned a number, then five problems were selected randomly employing a random number generator. The final math problems used in this study are listed in Appendix A.

The equated math problems were presented via a Delayed Match-to-Sample Task (DMTST). The participants were assigned to one of two conditions; an *Answer* or *Equation* condition. In both conditions' participants were asked to solve the same 5 math problems, however the problem characteristics differed depending upon assigned condition. In the *Equation Condition*, participants were given the answer, and then they were asked to choose the math equation to which the answer corresponds. An Example of a trial in the *Equation Condition* can be found in Appendix B. In the *Answer Condition* participants were given a math equation and then they were asked to choose the corresponding correct answer. An Example of a trial in the *Answer Condition* can be found in Appendix C.

A sixth problem was selected to be repeated three times after the original 5 problems. The repeated problem was employed as a manipulation check, because theoretically, cognitive effort should be minimal (no significant change in evoked HR) given the problem has been solved.

## **Procedure**

The study was first sent to the Institutional Review Board for approval and did not continue until approval was given (see appendix D). The approval code for the study was IRB-FY2019-109 on October 23<sup>rd</sup>, 2018. Upon arriving at the study, the participants were given a brief orientation to the study, then asked to read and sign a consent form (see Appendix E). Contingent on their consent to participate, each participant was asked to complete a brief Demographic Form (see Appendix F) assessing age and information that could have a direct effect on their respective HR (e.g., daily exercise, recent food and caffeine intake, medications, and any pre-existing cardiac conditions). These questions are based loosely upon conditions Strauss (2003) suggested affect HR. Once consent was obtained, the participant was given a shortened version of the quantitative portion of the WAIS in order to establish equality of math ability within conditions. Time to answer the WAIS math questions was used as an assessment of each participant's math ability.

Once the participant completed the WAIS questions, they were seated approximately 65 cm in front of the image display monitor, whereby the disposable electrodes were attached. The participants were asked to sit relaxed and quiet, and to restrict body movement. At this point, approximately two minutes of resting HR was recorded. An average of the resting HR was used to represent each participant's Baseline HR. Once the resting HR was established the DMTST began.

The DMTST was presented using a PowerPoint presentation. The presentation went as follows: a stimulus sample was presented for 5 sec, then an offset of the sample stimulus for 5 sec (a blank black screen was present), then the presentation of 4 test math problem solutions for 5 sec, however only one problem solution is correct. The participants were asked to select the

from the 4 test stimuli that matches the sample stimulus solution. RL was calculated from the onset of the 4 test stimuli to the verbal response from the participant selecting of one of the test stimuli.

For the *Equation Condition* the sample stimulus was the math equation and the 4 test stimuli were possible answers. Here the goal was for the participant to select correctly the test stimulus answer that corresponded to the sample stimulus equation. See Appendix B for an equation DMTST example. Conversely, in the *Answer* condition, the sample stimulus was the answer to the math equation. The test stimuli were 4 math equations. The goal was for the participant was to match correctly the test stimulus equation that corresponded to the sample stimulus answer. See Appendix C for an answer DMTST example. Both the *Answer* and *Equation* participants were given 5 novel DMTST math problems, and then the 6<sup>th</sup> DMTST problem was repeated for 4 more trials. The repeating problem is to establish a *post hoc* control (manipulation check) establishing that changes in HR are a function of cognitive effort.

## RESULTS

### Data Screening

Before analysis, the data was screened for accuracy to assure that the data were entered correctly. Two different researchers entered the data into separate excel spreadsheets. The researchers then checked the other data for accuracy, and the findings were compared. The data set was screened for accuracy again after the data was uploaded into SPSS. This last accuracy check found that none of the values were out of bounds and appeared to be correct.

The HR differences scores were calculated for all math problems in the form of  $(A - B)$  where  $A$  represents the participant's HR during the sample stimulus presentation and  $B$  represents the participant's baseline HR.

The data was then screened for outliers using Mahalanobis distance scores, and outliers were removed from the data set. Last, the data was screened for assumptions of linearity, normality, homogeneity, homoscedasticity, and additivity. It was found that all the assumptions were met.

### Demographics

The sample size for the *Answer Condition* was 19 participants, comprised of 7 females and 12 males. The *Equation Condition* sample size was 18 participants, comprised of 13 females and 5 males. The average age of the participants in the *Answer Condition* was 20.32 ( $SD = 3.73$ ) years, and for the *Equation Condition* the average age was 19.11 ( $SD = 1.45$ ) years. The two conditions also share the same median age of 19 years.

*WAIS math Ability Assessment.* Before data were collected via the DMTST, the participants completed a shortened version of the WAIS math subscale to assess their cognitive ability. The total time it took the participants to answer first 10 subscale problems was measured. The mean time (seconds) to complete the ten problems was 127.99 ( $SD = 37.21$ ) seconds. These scores were then converted to Z Scores, with a maximum score of  $z = 3.04$ , and a minimum z score of  $z = -1.54$ . No participant fell below 2 standard deviations from the mean when the scores were standardized. The participants that scored above 2 standard deviations were not removed from analysis due to the fact that they still had the cognitive capacity to solve the first-grade level math problems.

There were no differences between conditions on the math ability assessment. In the *Answer Condition*, the mean time to complete the math ability assessment was 124.86 ( $SD = 40.57$ ) seconds. In the *Equation Condition*, the mean time to complete the math assessment was 127.88 ( $SD = 34.19$ ) seconds. Based upon the results of an Independent *t*-test, no significant differences in math ability was found,  $t(35) = 0.49$ ,  $p = 0.63$ ,  $d = .08$ .

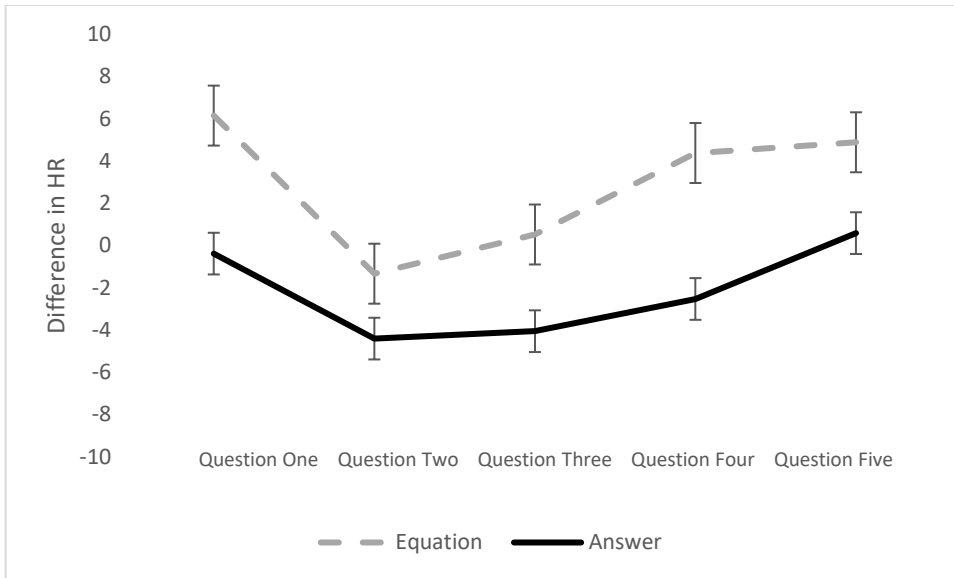
### **Primary Analyses**

There are three primary data analyses: (1) those to assess changes in evoked HR across DMTST math problems between and within the *Equation* versus the *Answer* Condition for the non-repeating and repeating math problems; (2) those to assess changes in RL across DMTST math problems between the *Equation* vs the *Answer* Condition for the non-repeating and repeating math problems; and (3) those used to explore the relationship between evoked HR and RL within the *Equation* and *Answer* conditions. The results of each of these analyses are presented in the following sections.

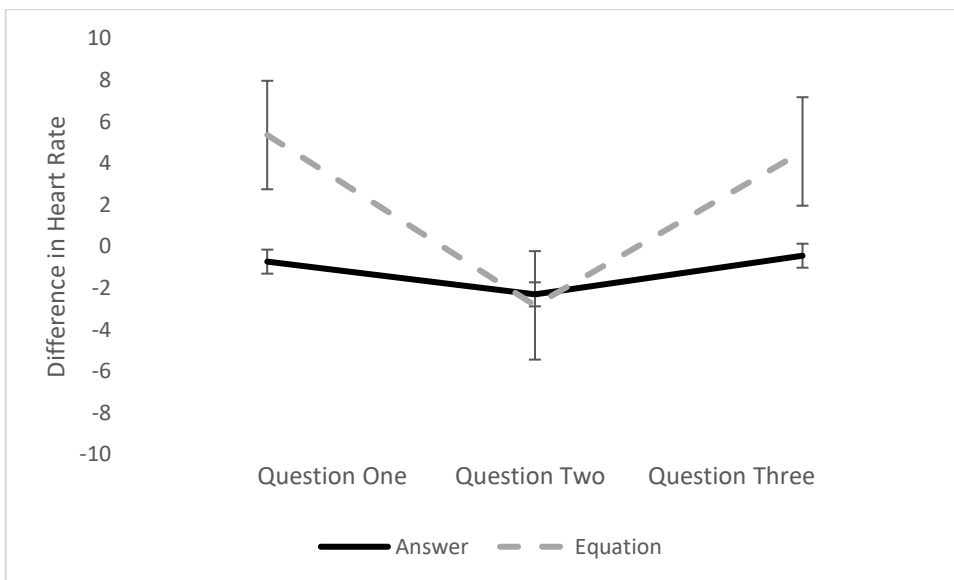


**Changes in Evoked HR across DMTST Non-Repeating Problems.** A 2 (Condition: Answer, Equation) X 5 (DMTST Math Problems) ANOVA with repeated measures on the last factor was calculated. The descriptive statistics for this comparison are presented in Figure 1. No significant interaction was evident ( $F(1,35) = .34, p = .85; \eta_p^2 = .02$ ). However, a significant main effect for *Condition* was found ( $F(1,36) = 4.88, p = .04; \eta_p^2 = .21$ ) indicating that the average evoked HR for the *Equation* condition was significantly lower than that of the *Answer* condition. Also, a significant main effect for *Question* was observed. ( $F(1,36) = 3.59, p = .02; \eta_p^2 = .17$ ). In order to assess the differences in the questions, two separate repeated measures ANOVAs were calculated, one for each of the conditions. For the *Equation Condition*, there were significant differences between questions ( $F(4,45) = 2.09, p = .05$ ). And based upon follow-up LSD *post hoc* comparisons, it was found that Question 2 had significantly lower evoked HR compared Question 1 ( $p = .02$ ). No other questions were found to have a significant difference. For the *Answer Condition* there were no significant differences between questions ( $F(4,49) = 1.73, p = .16$ ).

**Changes in Evoked HR across DMTST Repeating Problems.** A 2 (Condition: Answer, Equation) X 3 (DMTST Math Problem) ANOVA with repeated measures on the last factor was calculated. The descriptive statistics for this comparison can be seen in Figure 2. As predicted, no significant main effect of *Condition* ( $F(1,35) = 3.23, p = .06; \eta_p^2 = .17$ ) or *Question* was evident ( $F(1,36) = .02, p = .88; \eta_p^2 = .00$ ); and no significant interaction was observed ( $F(1,36) = .75, p = .75; \eta_p^2 = .01$ ). In summary, these findings lend support that HR is an indicator of cognitive effort. Since the problem was solved no substantial cognitive effort is need for solution, hence no change in evoked HR.



*Figure 1. Evoked Heart Rate During the Problem Presentation During Non-Repeated Stimulus: A line graph depicting the comparison of the difference in heart rate between conditions in the non-repeated questions in the portion of the trial where the problem was presented*



*Figure 2. Evoked Heart Rate Differ During the Problem Presentation During Repeated Stimulus: A line graph depicting the comparison of the difference in heart rate between conditions in the repeated questions in the portion of the trial where the problem was presented*

**Changes in Evoked HR within DMTST Problems.** Although HR can be evoked across problems, it is important theoretically to test changes within problems are significantly different from chance; above or below. To evaluate whether the evoked HR is significantly different than baseline, a series of One-Sample *t*-tests were calculated testing if the evoked HR was significantly different from zero. The inferential statistics for non-repeating problems by *Condition* are presented in Table 1.

*Table 1. Inferential Statistics for One-Sample t-test Comparison for Non-Repeated Stimulus: This table depicts the inferential statistics for a one-sample t-test comparison to zero for the non-repeated questions.*

Inferential Statistics for Non-Repeated Stimulus					
Condition	Question	Degrees of Freedom	<i>t</i> Statistic	<i>p</i> Value	Effect Size (Cohen's <i>d</i> )
Answer	One	18	-0.46	0.65	0.34
Answer	Two	18	-2.50	0.02	0.57
Answer	Three	18	-1.83	0.08	0.42
Answer	Four	18	-1.01	0.33	0.23
Answer	Five	18	0.26	0.80	0.06
Equation	One	17	2.10	0.05	0.49
Equation	Two	17	-0.88	0.39	0.21
Equation	Three	17	0.32	0.75	0.08
Equation	Four	17	1.53	0.03	0.54
Equation	Five	17	2.19	0.04	0.52

Although the numerous statistical tests increase the probability of a Type I error, conducting these are important theoretically, for the direction and magnitude of evoked HR

change represents the type of underlying cognitive activity. Given an alpha correction, none of the one-sample *t*-test can be viewed as statistically significant. However, the pattern (direction) of difference between the conditions fit with the predicted hypotheses. That is, HR acceleration was observed for the *Equation* condition HR deceleration was observed for the *Answer* condition.

The same series of one-sample *t*-test was conducted for the repeated problems. The inferential statistics for this comparison can be found below in Table 2. As can be seen on discernable difference in the magnitude or direction of evoked HR between the *Equation* and *Answer* conditions.

*Table 2. Inferential Statistics for One-Sample t-test Comparison for Repeated Stimulus: This table depicts the inferential statistics for a one-sample t-test comparison to zero for the repeated questions.*

Inferential Statistics for Repeated Stimulus					
Condition	Question	Degrees of Freedom	<i>t</i> Statistic	<i>p</i> Value	Effect Size (Cohen's <i>d</i> )
Answer	One	18	0.40	0.69	0.09
Answer	Two	18	1.77	0.09	0.41
Answer	Three	18	0.53	0.60	0.12
Equation	One	17	1.43	0.17	0.34
Equation	Two	17	0.65	0.52	0.15
Equation	Three	17	1.45	0.17	0.34

**Changes in RL across DMTST Non-Repeating Problems.** A 2 (Condition: Answer, Equation) x 5 (DMTST Math Problems) ANOVA with repeated measures on the last factor was

calculated. The descriptive statistics for this comparison can be found in Figure 3. A significant main effect for *Condition* was observed ( $F(1,35) = 4.31, p = .04; \eta_p^2 = .24$ , indicating that overall the *Equation* condition displayed faster RL than the *Answer* condition. No significant main effect for *Question* was observed ( $F(1,36) = 2.37, p = .15; \eta_p^2 = .15$ ) nor was there a significant *Condition* by *Answer* interaction,  $F(1,36) = .21, p = .66; \eta_p^2 = .02$ .

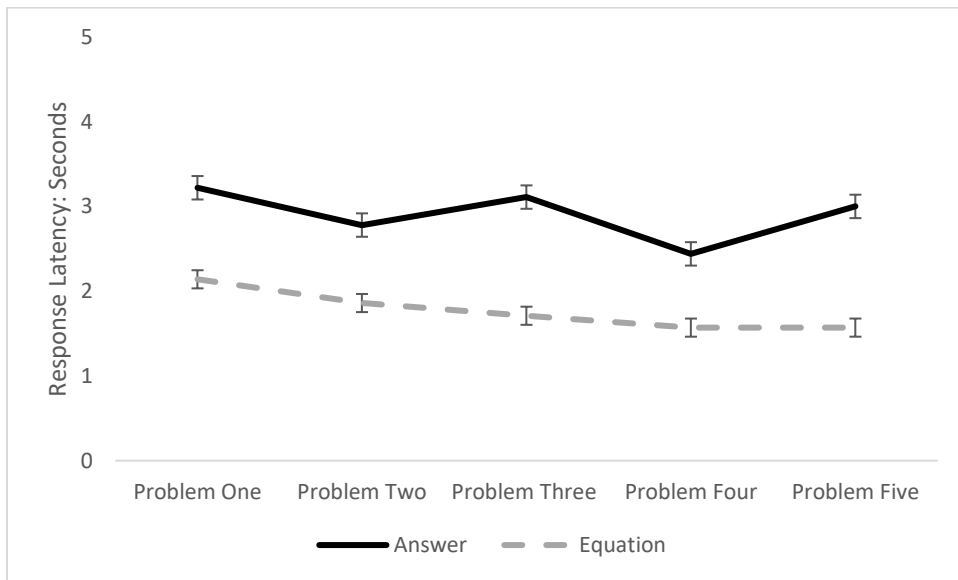
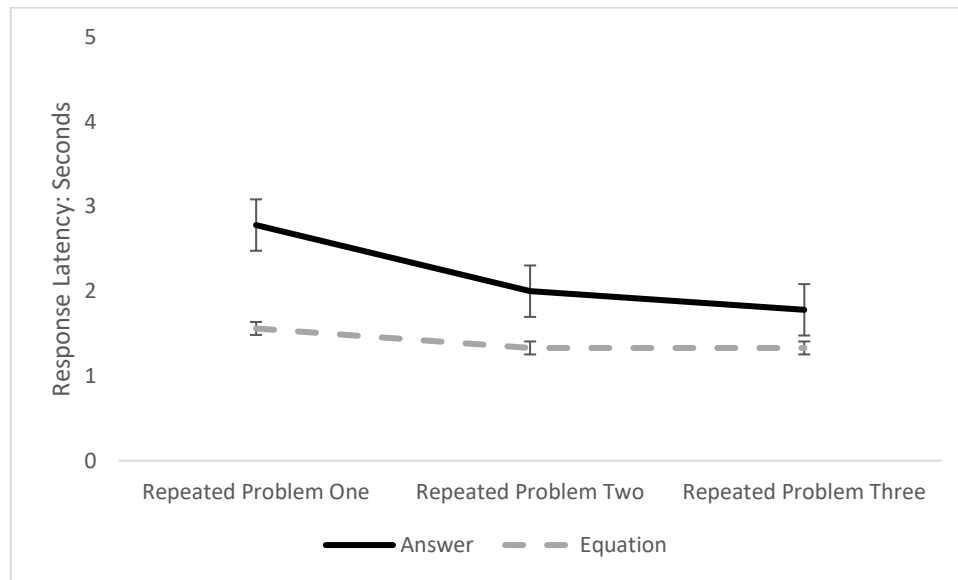


Figure 3. Response Latency Across Problems During Non-Repeated Stimulus: A line graph depicting the mean difference response latency

For the repeating problems a 2 (Condition: Answer, Equation) X 3 (DMTST; Repeated math problems) ANOVA with repeated measures on the last factor was conducted. The descriptive statistics for this comparison can be seen in Figure 4. No significant main effect for *Condition* resulted ( $F(1,35) = 2.17, p = .16; \eta_p^2 = .12$ ) and no significant interaction ( $F(1,36) = 2.64, p = .09; \eta_p^2 = .14$ ). However, there was a significant main effect for *Question* ( $F(1,36) = 6.98, p = .01; \eta_p^2 = .30$ ). Reviewing the mean RL for both conditions, it appears the difference is due to the slower RL on Question 1. To evaluate this effect, a second 2 (Condition: Answer,

Equation) X 2 (Question) ANOVA with repeated measures on the last factor was conducted with Question 1 removed. With Question 1 removed the main effect for *Condition* was not significant ( $F(1,35) = .99, p = .33; \eta_p^2 = .06$ ), and the main effect of *Question* was not significant ( $F(1,36) = .64, p = .44; \eta_p^2 = .04$ ). Hence, on Question 1 the participants were exhibiting some cognitive effort prior to solving the math problem.



*Figure 4. Response Latency Across Problems During Repeated Stimulus: A line graph depicting the mean difference response latency between the two conditions by question during the repeated problems.*

**Correlational Analyses: Relationship between HR and Subsequent RL.** A series for zero-order (Pearson) correlations were calculated within each condition between evoked HR and subsequent RL for each question. For the non-repeating problems, the Pearson Correlations for this comparison can be found below in Table 3 and for the repeating problems the Pearson Correlations are displayed in Table 4. Although these analyses were secondary and exploratory and the sample sizes are very small, the trends are in the expected direction. The greater the evoked HR the faster the RL. And when comparing the magnitude of the correlations for the

non-repeating versus that of the repeating problems, a predicted difference is observed. That is, the magnitude of the relationship between evoked HR and RL is stronger for the non-repeating math problems compared to the repeating math problems. Here again, suggesting that HR is an indicator of cognitive effort.

*Table 3. Zero-Order Pearson Correlations for Non-Repeated Stimulus: This table depicts the zero-order Pearson correlations for response latency and evoked heart rate for the non-repeated stimulus.*

Zero-Order Pearson Correlations for Non-Repeated Stimulus			
Condition	Question	Correlation	<i>p</i> Value
Answer	One	0.54	0.16
Answer	Two	0.51	0.16
Answer	Three	0.41	0.31
Answer	Four	0.34	0.41
Answer	Five	0.51	0.20
Equation	One	0.28	0.54
Equation	Two	-0.36	0.38
Equation	Three	0.66	0.05
Equation	Four	0.27	0.27
Equation	Five	0.36	0.28

*Table 4. Zero-Order Pearson Correlations for Repeated Stimulus: This table depicts the zero-order Pearson correlations for response latency and evoked heart rate for the repeated stimulus.*

Zero-Order Pearson Correlations for Repeated Stimulus

Condition	Question	Correlation	<i>p</i> Value
Answer	One	-0.12	0.77
Answer	Two	0.14	0.75
Answer	Three	-0.10	0.81
Equation	One	-0.15	0.71
Equation	Two	-0.12	0.75
Equation	Three	0.14	0.75



## DISCUSSION

### Evoked HR

It was hypothesized that evoked HR would be evidence of cognitive processing, and that in the *Equation Condition* participants would exhibit greater HR acceleration compared to those in the *Answer Condition*. This was due to the fact that we expected participants in the *Equation Condition*, who were given the problem first, would be engaging in some cognitive effort to solve that problem. We expected modest cognitive effort in the *Answer Condition* but did expect to observe primarily an anticipatory readiness to respond in the form of HR deceleration.

In summary, the predicted differences in evoked HR were observed, as can be seen in Figures 1 and 2. When first presented with the problem, the participants in the *Equation Condition* had evoked HR that was higher than baseline, which is argued to be a sign of increased cognitive effort. During this period, the evoked HR in the *Answer Condition* were at, or lower than the baseline. This observed decrease in evoked HR is argued to be a function of an anticipatory readiness to respond as opposed to cognitive effort. This finding would be in concordance with Lacey and Lacey's (1974) intake-rejection hypothesis. This makes sense because it was hypothesized originally that this pattern would emerge. The participants in the *Equation Condition* would display HR acceleration during the presentation of the problem, because they will be solving the math problem. When a participant is presented a first-grade level problem ( $4 + 8 =$ ), the participant will work to solve the math problem, and then employ some mental elaboration to hold the solution in memory until asked to select an answer from four options. We see the opposite pattern in the *Answer Condition*. When a participant is presented the answer during the presentation of the problem, the participant has no problem yet to solve,

hence no cognitive effort. However, anticipation and a readiness to respond develops, resulting in HR deceleration.

Further evidence that HR is an indicator of cognitive activity can be seen in the HR on the repeated math problems. No significant changes in HR were observed from baseline and no significant differences between conditions were observed. Since the problem solution has been solved, no cognitive effort or anticipatory response is required.

There was a *Question* effect in the first analysis. The evoked HR was greater for Question 1, particularly for participants in the *Equation* condition. It seems that math problem difficulty of the question would not account for this effect, given all questions were equated on level of difficulty. It is more likely that the response to Question 1 was a function of being the first question, and the participants were acclimating to the testing situation. It is still unclear whether Question 1 evoked this difference or if this difference occurred due to the placement of the problem. There were no differences between questions when the questions were repeated. It is important to remember that the repeated questions were all the same. There are no differences between questions in the other subsequent analyses, which supports further that the issue is not with the question itself.

These two factors of *Question* and *Condition* did not interact significantly in any of the analyses of HR. The effect size measures for the main effect of *Condition* accounted for approximately 21% of the variability between groups. This supports the finding that the two conditions are not only different statistically as a function of the problem manipulation, but also, this effect size is considered to be large and is in agreement with those reported in the literature. And comparing these effect sizes to those of the repeated questions lends further support that the observed *Condition* and *Question* HR differences are a due the math problem manipulation.

If cognitive effort was at play during the presentation of the problem, we would expect to see the *Equation Condition* with higher HR than baseline, and the *Answer Condition* would be at or below baseline. In order to assess this, each evoked HR mean was tested against chance (different from zero, meaning different from the baseline HR). The results were mixed, and only a few questions showed significant differences from zero. However, comparing the effect sizes of these tests, an interesting story arises. The average effect sizes for both conditions are very similar and show a medium effect (see Table 5), but the confidence intervals can be interpreted differently. Given that the 95% confidence interval for the *Answer Condition* includes zero we cannot be sure that there is any true difference in the evoked HR per question. But, in the *Equation Condition*, the 95% confidence interval does not include zero. This can be interpreted that the evoked HR is not equal to zero, although the results of the inferential statistics (the one-sample *t*-tests) represent no significant differences from zero. Therefore, applying the confidence interval summary for the Equation Condition, it is probable that the evoked HR per question represents a reliable change from baseline.

Using HR as an indicator of cognitive processing, we see that participants in the both conditions are engaged cognitively in DMTST. This makes sense, because in the *Equation* condition participants are solving the problem prior to being presented the answer options. We see an effect in the *Answer Condition*, however, it is argued that the magnitude of change is based upon an anticipatory response to select equation for which they were given the answer. This pattern is in line with the findings of Lacey and Lacey (1974), but due to the fact we have few significant differences we cannot conclude these results are a replication of the Lacey and Lacey intake-rejection hypothesis, however the predicted trend is present. Lacey and Lacey (1974) observed HR acceleration when participants were engaged in cognitive tasks (e.g.,

solving math problems), compared to HR deceleration when allocating attention (getting ready) to perform the math problem task.

*Table 5. Effect Sizes for Heart Rate Difference from Zero During Problem Presentation: A table depicting the average effect size and their 95% Confidence Intervals.*

Presentation of the Problem				
Condition	Measure of Effect	Effect Size	95% Confidence	
	Size	Obtained	Interval	
Answer	Cohen's <i>d</i>	1.08	0.27	1.85
Answer	Cohen's <i>d</i>	0.79	0.06	1.49
Answer	Cohen's <i>d</i>	0.58	-0.11	1.24
Answer	Cohen's <i>d</i>	0.32	-0.33	0.95
Answer	Cohen's <i>d</i>	0.08	-0.54	0.70
	<b>Average</b>	<b>0.57</b>	<b>-0.13</b>	<b>1.25</b>
Equation	Cohen's <i>d</i>	0.63	0.03	1.27
Equation	Cohen's <i>d</i>	0.27	-0.34	0.86
Equation	Cohen's <i>d</i>	0.30	0.15	0.69
Equation	Cohen's <i>d</i>	0.69	0.08	1.34
Equation	Cohen's <i>d</i>	0.66	0.09	1.30
	<b>Average</b>	<b>0.51</b>	<b>0.02</b>	<b>1.09</b>

## Response Latency

It was hypothesized originally that the magnitude of evoked HR would also be correlated with RL. That is, participants with greater evoked HR will have faster RL when solving the math problems. Overall, RL between the two conditions were significantly different, with the *Answer Condition* resulting in slower RL than the *Equation Condition*. When a math problem was repeated, no significant RL differences between the conditions were observed. This can be interpreted in that when cognitive effort is not required (the answer is known), differences in RL between conditions would not be expected.

On the repeating problems there were no significant differences in RL for the *Question*. This was surprising. It is difficult to tell why this occurred, because there are no differences at face value of these questions. When the repeated question was first presented, the participants took longer to respond, but the RL difference between questions diminished over trials; RL became faster. It is probable that the first presentation took some cognitive effort and visual search for the answer. On the subsequent repeated presentations, no effort is needed for the problem has been solved and no visual search for the answer is required, hence faster RL. This effect was consistent between conditions.

There were significant differences in RL between the *Answer* and *Equation* conditions on the non-repeating problems. It is not clear that the slower RL observed in the *Answer* condition was due to the participants having to search visually for the correct option and concurrently solve the math problem and then visual search for the correct equation and/or whether the participant is just taking longer to read? However, on the repeated problems, there were no significant differences in RL between the *Answer* and *Equation* conditions. There is obviously some difference in RL, however, given the possible confounds, the attentional processes that account

for individual differences in RL cannot be identified within the constraints of the employed research design.

### **The Relationship between HR and RL**

It was found that HR and RL did not correlate significantly. However, a consistent trend in the pattern of the relationship between evoked HR and subsequent RL resulted in both conditions. Moreover, the strength of the HR and RL relationships were weaker for the repeated problems. Although these correlational analyses were exploratory, the results do support the connection between HR and RL that could be important theoretically in the study of cognitive processing.

### **Limitations**

One major limitation of this study is the small sample size (underpowered). Therefore, the probability of a Type 1 error increases. This limitation could be corrected by collecting more data and/or by replication. However, the observed effect sizes and the standard errors between conditions provide evidence the probability of Type 1 errors are low.

Another limitation of this study is that the majority of the sample was female and the majority were white. This makes it difficult to generalize the results to all demographics. The sample was also comprised of college-aged students, which makes it difficult to generalize to other populations (e.g., children and older adults). While the hypotheses were not expected to be different between demographic groups, the generalization of these findings are limited.

### **Future Research**

First, it could be interesting to assess the effect of math anxiety on RL and the magnitude of subsequent physiological responses. Partialing out the effect of math anxiety could be a start to identify the contribution of cognitive processing during math problem solving. Which in turn, could better define the changes in HR as an indicator of cognitive activity.

Future research could also implement math problems of increasing difficulty, instead of using first grade level math problems. By varying math difficulty, individual differences in math solutions could be more readily identified. Belmont and Mitchell (1987) argued that to investigate individual differences in cognitive strategy use, one has to identify problems that are at an optimal level of difficulty. Otherwise, problems that are too easy or too difficult no strategy use will be observed. According to Belmont and Mitchell (1987) without determining appropriate levels of math difficulty, accurate measurement of cognitive processing differences and how such processes relate to problem solving would be unattainable.

One final suggested approach to studying individual differences in math problem solving is application of eye tracking technology. Replicating this study employing eye tracking technology could provide a unique assessment of how participants are actually solving math problems. Eye tracking technology provides a means of measuring where attention is directed, number of fixations, fixation durations, and latency to attend to stimulus areas. Using such eye movement measures would allow a detailed analysis of the components of the math formulas, which could permit insights into the learning process, as well as insights into cognitive processing that is unavailable typically to measure. Also, eye tracking would permit an observational map of participants' problem solving behavior when making match-to-sample choices. Such could further a working knowledge of individual differences in math ability, which in turn could afford the designing of appropriate math teaching methods.

## Conclusions

The findings, for the most part, were in the direction as hypothesized. And too, the results provide further theoretical support regarding the magnitude and direction of evoked HR during problem solving.

Overall, RL was found to be significantly different between conditions, with the *Answer Condition* having slower RL compared to the *Equation*. It was hypothesized that RL would be due to cognitive effort, but it is difficult to make the distinction between cognitive effort and the possibility of just taking longer to read, especially during the match-to-sample in the *Answer* condition. For during the match-to-sample selection, not only does the participant have to process the equation and solve the math problem, but has to search visually for the correct option. The cognitive effort hypothesis is supported by the evoked HR being higher, but evidence is lacking to explain individual differences in RL. In sum, it is the contention of the author that the use of HR as a measure of cognitive processing shows promise, for both the study of individual differences in cognition as well as testing cognitive theory.



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## APPENDICES

### Appendix A: Problems Utilized in Stimuli

$$4 + 8 =$$

$$7 + 4 =$$

$$7 - 5 =$$

$$4 / 2 =$$

$$21 + 5 =$$

$$6 / 2 = \text{(repeated problem)}$$

**Appendix B: Stimulus Equation Condition**

$$3 + 4 =$$

8

7

3

6

## Appendix C: Stimulus Answer Condition

7

$$2 + 6 =$$

$$3 + 4 =$$

$$3 + 5 =$$

$$8 + 1 =$$

## Appendix D: Institutional Review Board Approval



**To:**  
D Mitchell  
Psychology

**RE:** Notice of IRB Approval

**Submission Type:** Initial

**Study #:** IRB-FY2019-109

**Study Title:** Heart Rate, Attention, and Quantitative Reasoning

**Decision:** Approved

**Approval Date:** October 23, 2018

**Expiration Date:** October 23, 2019

This submission has been approved by the Missouri State University Institutional Review Board (IRB) for the period indicated.

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Federal regulations require that all research be reviewed at least annually. It is the Principal Investigator's responsibility to submit for renewal and obtain approval before the expiration date. You may not continue any research activity beyond the expiration date without IRB approval. Failure to receive approval for continuation before the expiration date will result in automatic termination of the approval for this study on the expiration date.

You are required to obtain IRB approval for any changes to any aspect of this study before they can be implemented. Should any adverse event or unanticipated problem involving risks to subjects or others occur it must be reported immediately to the IRB.

This study was reviewed in accordance with federal regulations governing human subjects research, including those found at 45 CFR 46 (Common Rule), 45 CFR 164 (HIPAA), 21 CFR 50 & 56 (FDA), and 40 CFR 26 (EPA), where applicable.

Researchers Associated with this Project:

**PI:** D Mitchell

**Co-PI:**

**Primary Contact:** Abigail van Nuland

**Other Investigators:**

## Appendix E: Informed Consent Form

### Missouri State University Consent of Participation Infant Perception and Learning Laboratory

This study is part of the Missouri State University Psychology Graduate Program designed to give us more information and to fulfill a thesis requirement for Abigail Van Nuland. The following information is provided so that you can decide whether you wish to participate in this study. If you agree to participate, you will (not necessarily in this order) complete a brief baseline task and demographic questionnaire, and we will observe your visual responses, and corresponding heart rate, to series of math problems. During the viewing you will have 3 electrodes attached to you (one on each of your ankles and one on your right wrist) so to record and monitor your heart rate. One of the members of the research lab should have explained the purposes and procedures of the study to you and will answer any questions you might have. Please be assured that if you agree to participate, you are free to withdraw from the study even after you have signed this consent form. If you wish to withdraw, simply stop any on-going task and tell the research staff you wish not to continue. Should you decide to terminate the research session; all data pertaining to you that have been collected will be destroyed.

There are no anticipated risks in this study that are outside those encountered in everyday life. You have the right to withdraw from the study at any time in order to remove any chance of psychological harm if they feel uncomfortable. You will benefit by receiving credit for your introductory psychology course and will also benefit by contributing to science. Due to the fact that there are no risks outside those associated with day to day life, the participant is not taking a risk when participating in this study and is within reasonable limits. The benefits of participating in this study greatly outnumber the risks. This session has been scheduled for approximately one hour, and we anticipate taking up that whole period of time.

Since it is our policy to protect the confidentiality of all our participants, your name will not be included in any data analyses, subsequent publication or presentations related to this research study. All raw data collected during this study will be identified only by code-number to ensure confidentiality of the information collected.

If questions arise after you have left the research laboratory, feel free to give D. Wayne Mitchell, Ph.D. a call at 417-836-6941 or at [waynemitchell@missouristate.edu](mailto:waynemitchell@missouristate.edu). We do not anticipate any risk to you as a result of participating in this study, but it is unlikely that this study will provide you with any direct benefits. Your participation will, however, make an important contribution to our scientific knowledge, and we very much appreciate your cooperation.

I have read the above description of the study and I agree to participate.

Participant's Name (please print): \_\_\_\_\_.

Participant's Signature: \_\_\_\_\_.

Witness's Signature: \_\_\_\_\_.



## Appendix F: Demographics Questionnaire

1. Participant Number
2. Baseline Task Time
3. How old are you?
4. What is your gender?
5. What time did you last eat?
  - a. Briefly describe how much you ate?
6. Have you had caffeine in the past 3 hours
  - a. Approximately how much
7. Are you currently taking any cold medicine, allergy medicine or prescribed medicine?
  - a. Please explain
8. Do you exercise regularly
  - a. How often and how long
  - b. What type of exercise
9. Do you smoke?
  - a. On average, how much do you smoke?
10. What mode of transportation did you use to get to the study?