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Learning in the context of math anxiety

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LEARNING IN THE CONTEXT OF

MATH ANXIETY

by

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ABSTRACT

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Previous studies have examined the effects of math anxiety on working memory and performance. It has been shown that having a high level of math anxiety not only decreases performance, but also interferes with working memory such that the anxiety competes for working memory resources, decreasing the amount of working memory resources available to work on a math task. Previous research has focused on the semantic memory approach, i.e., testing people on what they already know. The current study took this research one step further and looked at learning, specifically stimulus learning, in the context of math anxiety. A well studied lab task, the true/false verification task, was adapted to study learning on the part of individuals who vary in their math anxiety. Some of the addition problems were shown only once to participants while other addition problems were shown nine times. One prediction of this study was that low math anxious individuals would be able to learn more mathematical information across blocks of trials than high math anxious individuals, and would demonstrate this on a recall test of incidental learning after three blocks of making true/false judgments to simple addition problems. Although this learning effect between high and low math

anxious individuals was not found, another interesting effect was discovered with regard to the learning recall task. High math anxious participants learned more of the false answers with large splits than the low math anxious participants. This was an unexpected finding, and one inference that could be drawn from this is that low math anxious participants are not looking at the false problems with the large splits long enough to encode them, whereas the high math anxious individuals may be looking at the problem longer, unable to quickly judge it as false.

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CHAPTER 1

INTRODUCTION

Over the past thirty five years, researchers have become increasingly interested in the topic of math anxiety. Math anxiety involves discomfort and nervousness that can result from a situation dealing with numbers or a situation involving simple calculations. It can be felt in a math classroom, in a restaurant, and even in the comfort of one's own home while trying to balance a checkbook. Having this specific type of anxiety has been found to correlate with students avoiding math classes as well as avoiding careers involving math (Hembree, 1990).

Since 2001 several studies have investigated the consequences of math anxiety as it relates to gender (Miller & Bichsel, 2004), education (Chen & Geng, 2002), cognition (Ashcraft, 2002), and performance (Ashcraft & Kirk, 2001). With all of this research that has looked at math anxiety and performance and math anxiety and working memory, little work has been done to see what effect math anxiety may have on the learning and storage of math facts in memory. In this thesis, math anxiety as it relates to the learning and storage of math facts was investigated.

Before discussing the thesis experiment and its results, a detailed review of the literature will take a comprehensive look at math cognition to show what has been found in terms of how children and adults comprehend numbers as well as the different strategies they use to tackle different types of math problems. The review will then cover research that has examined the relationship between math cognition and working memory. Once an understanding of the theories and models behind math cognition and working memory has been established, the literature review will turn to examine the initial research on math anxiety as well as the relationship between math anxiety and working memory, the development of the Math Anxiety Rating Scale, and the possible causes and consequences of having math anxiety. Finally, the experiment for this thesis project will be explained, results will be given, and a discussion will follow

CHAPTER 2

LITERATURE REVIEW

Math Cognition

Some of the first pioneering work involving how both children and adults thought about math and exactly how math problems and processes were mentally represented was found in the work of Parkman and Groen (1971) and Groen and Parkman (1972). In the 1971 study, they gave college students a yes/no verification task in which the participants looked at simple addition problems of the form a + b = c, where c was a double digit sum, and pushed the yes button if the equation was correct and pushed the no button if the equation was incorrect. For the incorrect equations, the answers were wrong by not more than ±2. Results of the experiment indicated the problem size effect; reaction time latencies increased as both a function of minimum addend and sum (Parkman & Groen, 1971). Reaction time latencies for tie problems (6 +6) were also found to be significantly faster than for nontie problems. The authors indicated that adults may be performing simple addition problems in the same way that children were, only the process had become automated and much faster; however, more reaction time data for children was needed before that conclusion could be confirmed (Parkman & Groen, 1971).

In 1972, Groen and Parkman set out to obtain more evidence with regard to children performing simple addition. They considered several counting models for first grade children who were attempting to solve simple addition problems (problems with single digit addends and sums of less than or equal to nine). The five predicted models were tested using data obtained with a production task. Participants had a box with the numbers one through nine on it. A problem was presented to them, they then had to calculate the answer and press the numbered button that corresponded to the correct sum. This was in contrast to the verification task used in the 1971 Parkman and Groen experiment in which the participant would be shown the problem with an answer, and they would simply have to verify whether the answer provided made the equation true or false. After testing all five predicted counting models, the results showed that, in the first grade, children were using what Groen and Parkman referred to as a "count by min" model for solving simple addition problems. According to the "count by min" model, a first grader would solve the problem X + Y = ? in the following manner: first, a mental counter would be set to the larger of the two addends (max(X,Y)). The child would then count up by the minimum addend (min(X,Y)) one step at a time to achieve the answer. For example, given a problem such as 5 + 2, the child would hold the larger addend, 5, in memory, and then increment by 1s until the number of increments equaled the minimum addend, 2. One exception found in the study was in the case of tie problems. Tie problems all appeared to have the same reaction time latency, and the authors stated that children must have been using some type of retrieval system for tie problems, indicating that those answers were already stored in memory.

After the conclusion of the study, there were two possible ideas presented about how adults might have been processing simple addition problems; one idea was that the process for adults would be the same as that for the first graders, only faster (Parkman & Groen, 1971). There were some discrepencies between the data, however, that did not fit with that idea. Firstly, even though the minimum addend provided the best fit, for the adult data, the sum of the problem accounted for almost as much of the variance as the minimum addend. Secondly, with adults being extremely faster than children, it did not seem that adults were incrementing by counting to themselves, and that meant that if adults were incrementing, then they were doing it by some unknown mechanism (Groen & Parkman, 1972). Those discrepancies led to a rejection of the idea that the simple addition process for adults and children was the same. A second idea was that adults would use the same reproductive process that children used for tie problems on most simple addition problems; however, for an unknown proportion of simple addition problems, adults would revert back to the counting model used by children (Groen & Parkman, 1972).

Evidence pointing to a direct retrieval process in adults came from Parkman (1972). An experiment was conducted to try and extend the "count-by min" model to multiplication. In the experiment, college students were given a verification task in which they were given a single-digit multiplication problem with an answer ($p \times q = r$), and they had to respond whether the equation presented to them was true or false. The latencies increased as a function of min(p,q) and as a function of the sum of p and q; that result showed the problem size effect. This was the same effect found for simple addition in Groen and Parkman, 1972. It seemed that simple addition and multiplication were governed by the same underlying processes (Parkman, 1972). However, to interpret the new findings for multiplication in terms of the "count-by min" model, the participants would need to be counting-on as indicated by the larger multiplier; for example, in the case of 7 x 3, an individual would count-on by 7s for 3 increments (Ashcraft, 1992). In comparing the count-by min model for simple addition to the same model for multiplication, it was pointed out that the restriction of incrementing by 1s for addition did not make sense if for multiplication, one could count-on by 7s (Miller, Perlmutter, & Keating, 1984). In the discussion section, Parkman (1972) talked about the limitations of the "count-by min" model and wrote that if single-digit multiplication was assumed to be achieved through a process of direct retrieval, then single-digit addition would also seem to operate under that same process.

In 1978, the ideas given regarding adults' processing of simple addition problems by Groen and Parkman (1972) were tested by Ashcraft and Bataglia in two experiments using college students as participants. In the first experiment, simple addition problems with answers were presented in a true/false verification task. For the false problems, the authors investigated the split effect. Originally, the term split was used to describe the distance between two digits presented on a mental number line. If a participant was presented with two digits, he/she would use a mental number line to compare the two digits and decide which one was larger (e.g. Moyer & Landauer, 1967). For the Ashcraft and Bataglia study, the split effect was manipulated in the answers of the false stimuli presented such that some of the false answers were different from the real answer by ±1or 2 (termed reasonable false) and other false answers were different from the real answer by ±5 or 6 (termed unreasonable false).

The results of the first experiment did not lead to evidence of a strictly counting model in adults. Unlike the previous results, which indicated the minimum addend to account for most of the variance (Groen & Parkman, 1972), the first experiment found that 48% of the variance was accounted for by the square of the correct sum for true and reasonable false problems, indicating the problem size effect. Also found was that the minimum addend was only the best predictor for unreasonable false problems. According to these results, a strictly counting model for adults did not make sense because the squared term accounting for most of the variance could not be made to correspond with a counting factor as proposed in the "count-by min" model (Ashcraft & Bataglia, 1978).

To test that result thoroughly, the second experiment in the study used the same stimuli as the first experiment with the exception of some repeated stimuli. The authors investigated what happened to reaction times when the stimulus was repeated in its entirety, when only the sum was repeated, and when either the first or the second addend was repeated. Results indicated that the reaction times were significantly decreased when the problem was repeated in its entirety, and that even when only the sum was repeated, reaction times were facilitated (Ashcraft & Bataglia, 1978). These repetition effects provided direct evidence against a strictly counting model for adults in that Groen and Parkman's 1972 "count-by min" model could not explain the facilitation in reaction times that occurred when exactly repeated stimuli were presented. A network retrieval model was posited in which the network representation for addition was a square with the digits 0-9 on two adjacent sides and the sums located at the intersection point of any two numbers. Incorporating the exponential problem size effect, modifications to the square were presented that included stretching out the distance between larger sums or making the distance between entry sums larger as the addends got larger (Ashcraft & Bataglia, 1978).

To examine the various models for mental addition, a study was conducted which tested the strictly counting model, the direct access model with backup counting (Groen & Parkman, 1972), and the network retrieval model (Ashcraft & Bataglia, 1978) of adults processing of mental addition (Ashcraft & Stazyk, 1981). The results showed that reaction times again increased with problem size and also decreased with increased split in the false answers. These results were consistent with the network retrieval model proposed by Ashcraft and Bataglia, and they did not refute the network representation scheme proposed in that study.

By the early 1980s, it had been shown that first graders used a "count by min" model (Groen & Parkman, 1972) and that adults were using a network retrieval model (Ashcraft & Bataglia, 1978, Ashcraft & Stazyk, 1981). Researchers were beginning to wonder exactly where the transition occurred from a counting model in the first grade to a retrieval model in adulthood. In 1982, Ashcraft and Fierman conducted a study to try and investigate that very question. The experiment consisted of simple addition problems presented to third, fourth, and sixth graders for a true/false verification task. Results showed that half of the third graders were using a counting process and the other half were using retrieval methods indicating that there may be a transition occurring from counting to retrieval happening in the third grade. Fourth and sixth graders were found to have similar reaction time profiles to adults indicating a retrieval method, and, although fourth graders were still slow to judge the false problems, sixth graders were found to perform the same as adults. Analyses showed a switch from the minimum addend being the best predictor to the correct sum squared being the best predictor starting in the third grade and the correct sum squared being the best predictor from then on.

Another interesting finding arose when the math textbooks of elementary schools were examined to see what kinds of simple addition problems were shown most frequently. The results showed that small problems were presented much more frequently than large problems (Hamann & Ashcraft, 1986). This result gave evidence in favor of the network representation scheme presented by Ashcraft and Bataglia in 1978. Small problems had stronger network representations due to experience and lots of practice, resulting in shorter reaction times. Also, longer reaction times, indicating weaker network representations for large problems, could be explained by a lack of experience and practice beginning from the initial learning of simple addition.

As more researchers became interested in math cognition and the mental processes involved in performing math tasks, more evidence was found confirming repetition effects (LeFèvre, Bisanz, & Mrkonjic, 1988). Also, evidence was found that challenged a strictly retrieval model for adults' processing of simple addition problems (LeFevre, Sadesky, & Bisanz 1996). Lefevre et al. found that the strategies used by adults depended on the characteristics of the task. In fact, it was found that the size of the problem affected exactly which strategies adults would choose to use (LeFevre et al., 1996). As the problems got larger (having a sum greater than 10), adults were just as likely to use a procedural strategy as a retrieval strategy. Reaction time data obtained by Lefevre et al. (1996) showed slower reaction times when participants reported using procedural strategies and faster reaction times when participants used retrieval strategies.

Another result showed that if the minimum addend was 1, 2, or 3, the participant was most likely to report using a counting strategy.

In 2001, Kirk and Ashcraft performed two experiments to further investigate the results obtained by Lefevre et al. (1996). The first experiment replicated the conditions in Lefevre et al. (1996) with the addition of two contrasting instruction conditions and a silent control condition. Instruction conditions consisted of four groups: retrieval bias, strategy bias, replication, and silent control. The results showed a verbal report bias based on which instructions the participant received; those participants who had been biased to report direct retrieval strategies did so 90% of the time, and those participants who were biased toward non-retrieval strategies showed a higher increase in reporting non-retrieval strategies in their verbal reports as well. The second experiment replicated the first with the exception of using multiplication problems instead of addition problems; all instructions were also changed to accommodate multiplication. Once again, the results showed that participants' verbal reports were biased when given demand instructions. Overall, demand instructions were shown to play an important role in participants' verbal reports which was not an accurate reflection of their cognitive processes (Kirk & Ashcraft, 2001).

Summary of Math Cognition Research

So it has been shown that children in the first grade use a "count by min" model (Groen & Parkman, 1972); however, a transition occurs somewhere in the third grade where children are switching from the "count by min" model to a retrieval model for simple addition (Ashcraft & Fierman, 1982). Different results have been obtained with regard to the performance on simple addition problems by adults. One result indicated that adults used various strategies as a function of problem size (LeFevre et.al, 1996). Other results pointed to adults using a strictly retrieval model to perform simple addition tasks (Ashcraft & Bataglia, 1978, Ashcraft & Stazyk, 1981).

Since the evidence points to frequent, but not continuous use of a direct retrieval strategy, it would be good to examine why adults may be choosing procedural strategies or why some adults may just be taking longer to retrieve the solution. One explanation can be found by looking at math cognition through a model for working memory. The next section will give an explanation of the working memory model for which the framework of the current study is based. Research examining the relationship between math cognition and working memory will also be discussed.

Math Cognition and Working Memory

Working memory involves the temporary storage and processing of information. Cognitive psychologists looking at working memory typically look at it in terms of Baddeley's (1986) working memory model. There are three parts to the working memory model: the central executive and two storage systems (the visuospatial sketchpad and phonological loop). The central executive acts as the supervisory system; it initiates retrieval from long term memory and controls the information going to and from the visuospatial sketchpad and the phonological loop. The phonological loop deals mainly with auditory verbal information such as remembering somebody's name that you just met, and the visuospatial sketchpad is involved with visual and spatial information such as how fast an object is moving or where it is located. Recently, Baddeley (2000) has added a fourth component to the model, called the 'episodic buffer'. This component is a third storage system, dedicated to linking information across domains to form integrated units of visual, spatial, and verbal information.

According to Baddeley's working memory model, working memory only has a limited number of resources to work with at any one time, allowing only a certain number of tasks to be done at the same time. Sometimes more than one task can be accomplished at the same time; however, it depends on which subsystems of the central executive are involved and if there is competition for any of the working memory resources. It is easier to do two tasks, each relying on a different subsystem of the central executive (i.e. a verbal and a spatial task), than it is to do two tasks in which each task is relying on the same subsystem (i.e. two spatial tasks) (Baddeley & Hitch, 1974).

By the early 1990s, questions were being asked as to the involvement of working memory in the process of solving arithmetic problems. One experiment aimed at investigating the role of working memory in addition was conducted by Ashcraft, Donley, and Halas (1992). The authors used both single digit and two column addition problems for a true/false verification task. Three concurrent tasks (repeat, alphabetization, and word generation) were also presented to each participant. For the single digit addition problems, it was found in the word generation and the alphabetization tasks that the participants exhibited slower verbal performance, which implicated working memory in the process of simple addition. The two column addition problems showed an even stronger reliance on working memory; the interference of the concurrent task was evident, especially when the carry operation was required (Ashcraft et al., 1992). Although working memory was shown to be involved in both single and two column addition problems, specific subsystems of the working memory model (the central executive, phonological loop, and visuo-spatial sketchpad) were not discussed.

Several studies provided evidence that the central executive is involved in solving single-digit arithmetic problems. In 1996, a study was done with the intention of finding out which parts of the working memory system were active when adults performed simple addition problems. Lemaire, Abdi, and Fayol used college students in their experiment and gave them simple addition and multiplication problems in a true/false verification task. For a subset of the false problems, confusion problems were presented; confusion problems were considered those problems in which the proposed answer matched a correct answer to another problem or was correct under another operation (i.e. 3 + 4 = 12 or 3 x 4 = 7). Another subset of false problems did not contain confusion problems. The authors did not manipulate split for the experiment, and easy and difficult problems were determined using a difficulty rating scale (Ashcraft's index; see Hamann & Ashcraft, 1985). One of four memory load conditions was assigned to participants: control, articulatory suppression, canonical letters, and random letters. In the articulatory suppression condition, participants were asked to repeat a word over and over to try and interfere with the phonological loop. The canonical letter condition involved the participants repeating the letters "abcdef" over and over. Finally, in the random letter condition, participants had to constantly repeat a random combination of the letters "abcdef." Results showed longer latencies between easy and difficult problems in the random letter condition as well as higher error rates for confusion vs. nonconfusion problems in the random letter condition (Lemaire et.al, 1996). These findings from their first experiment led the authors to conclude that the central executive was indeed involved in adult's solving of mental arithmetic problems.

In their second experiment, Lemaire et.al (1996) replicated the first experiment with the exception of showing participants either addition problems or multiplication problems, but not both. Also, participants were randomly assigned to an operation by load condition. Operations consisted of addition or multiplication and loads consisted of articulatory suppression, canonical letters, or random letters. Results were consistent with the first experiment and indicated that an overload of one slave system, the phonological loop, implicated the central executive as being involved in the process of mental arithmetic in adults. One weakness of the experiment was that the role of the phonological loop itself in mental arithmetic was not discussed; only its implications with regard to the central executive were mentioned.

In 2001, De Rammelaere, Stuyven, and Vandierendonck attempted to investigate the exact role, if any, that the phonological loop was playing with regard to adult's processing of mental arithmetic problems. Experiment one consisted of only simple addition problems presented for true/false verification, and the split effect was also examined with reference to small splits (±1) and large splits (±9) (De Rammelaere, Stuyven, & Vandierendonck, 2001). There were three load conditions: A control condition, an articulatory suppression condition in which the participant had to repeat a word over and over (designed to overload the phonological loop), and a random time interval rhythm generation condition (designed to overload the central executive). Results indicated that the phonological loop was not involved because the articulatory suppression task did not interfere with the verification task; however, the rhythm generation task did interfere with the verification task which confirmed that the central executive was highly involved in adult's processing of mental addition problems (De Rammelaere et.al, 2001). Their second experiment resulted in the same conclusions for simple multiplication problems. Although it showed that the central executive had a general effect on processing, it was not clear which aspects in particular were important to arithmetic.

Summary

After several studies, it was clear that the central executive was involved in arithmetic processes. Evidence also suggested that the phonological loop was not involved in solving arithmetic problems. As this work was being completed, a new area of research was being looked into involving math anxiety. The next section will introduce the math anxiety rating scale as well as discuss some previous research and findings in the area of math anxiety.

Math Anxiety and the Math Anxiety Rating Scale

As mentioned in the introduction, math anxiety involves discomfort and nervousness that can result from a situation dealing with numbers or a situation involving simple calculations. In 1972, Richardson and Suinn developed a scale with which to measure an individual's level of math anxiety. Named the Math Anxiety Rating Scale (MARS), the scale contained 98 items, each describing a situation dealing with math. Some situations were academically oriented (e.g. taking a math test) while others referred to situations encountered in everyday life (e.g. making change). Using a five point Likert scale, participants rated the level of anxiety that they would feel in those situations.

Due to the length of the scale and the time that it took participants to complete it, a shortened version of the MARS was developed that consisted of 25 items (Alexander & Martray, 1989). To make sure that the newly shortened version was representative of the 98-item original, an experiment was conducted which found the 25-item scale to be highly correlated ($r = .96$) with the original 98-item MARS (Fleck et. al, 1998). The sMARS, as Fleck et. al (1998) termed the 25-item scale, is now the most widely used scale to measure math anxiety.

Math Anxiety Research

Math anxiety researchers have looked at achievement tests to examine how math anxiety affects performance on math tasks. One such math achievement test used in math anxiety experiments is the Wide Range Achievement Test (WRAT), which was developed by Jastak and Jastak (1978). For the first three lines of the WRAT, which consist of whole number simple addition, subtraction, multiplication, and division problems, Ashcraft and Kirk (1998) found that low, medium, and high math anxiety groups performed equivalently. This indicated that all participants, regardless of math anxiety level, had the same level of achievement when performing simple mathematical procedures. However, group differences did begin to appear on lines 5 and 6 where the problems consisted of fractions, decimal arithmetic, and long division with a remainder. The largest group differences were seen on the last line, consisting of functions and factoring procedures, where low math anxious participants averaged 1.9 correct out of 5, versus 0.5 correct out of 5 for high math anxious participants (Ashcraft & Kirk, 1998).

Another study done in 1994 by Ashcraft and Faust investigated what level of math tasks was needed to start to seeing math anxiety interfere with computation of the math task. The results indicated that two-column addition problems involving carrying were sufficient to have math anxiety effects. The high math anxious groups had much slower reaction times to computing carry problems than the low math anxious group, indicating that the math anxiety experienced by the high math anxious groups was interfering with their ability to do the computation involved in a carrying problem. This result was the first of its kind to be reported in the literature (Faust, Ashcraft, & Fleck, 1996).

A disturbing finding by Faust et al., (1996) was that individuals with high math anxiety experienced what the authors termed to be a speed-accuracy trade-off. According to the authors, the high math anxious participants exhibited faster reaction times than the medium math anxious participants; however, the accuracy of the high math anxious participants was dismal compared to the medium math anxious participants. They concluded that, to get through the discomfort of completing the math task, the high math anxious individuals were hurrying through the problems in an attempt to relieve their anxiety, allowing their accuracy to diminish along the way.

After seeing some of the findings regarding math anxiety, it was logical to follow in the footsteps of the math cognition research and examine what, if any, effects math anxiety was having on working memory. Research examining the relationship between math anxiety and working memory is covered in the next section.

Math Anxiety and Working Memory

As illustrated by Eysenck (1992), general anxiety interferes with working memory resources and this is reflected in the slow and/or inaccurate performance of a task. By that time, several researchers were already studying math anxiety; however, Eysenck gave them a new perspective about what might be going on with individuals who experience math anxiety. Later, researchers applied Eysenck's (1992) idea to math and discovered that anxiety and the math task were both competing for the same pool of working memory resources. From there, a pool of research developed examining exactly how the math anxiety was interfering with working memory and specifically which kinds of tasks caused the interference to be present.

Math anxiety can be understood in the context of Baddeley's (1986) working memory model. The math task being done is taking up working memory resources, and the anxiety associated with the math task is also taking up working memory resources. In other words, the anxiety is competing with the math task for the available working memory resources. Eysenck (1992) found that the higher the level of general anxiety, the less people were able to perform a second task requiring working memory resources. From that result it was deduced that the higher the level of math anxiety, the more resources will be needed from working memory, leaving little or no resources left to solve the math task presented. With these ideas in mind, several research studies investigated the relationship between math anxiety and working memory.

In 1998, Hopko, Ashcraft, and Gute, conducted an experiment in which a reading task was used to examine whether math anxiety would disrupt normal processing with regard to the working memory system. Participants were assessed using the sMARS, and they were then categorized as low, medium, or high math anxious. They were then randomly assigned to one of three reading conditions consisting of either math or non-math paragraphs as well as different distracter types: control, unrelated (distracter words that were unrelated to paragraph content), and related (distracter words that were related to paragraph content). Results showed that high and medium math anxious participants had much slower reading times when there were distracters present than the low math anxious participants. The high math anxious participants also made more errors on the comprehension questions than did the low math anxious participants (Hopko et.al, 1998). Although it was shown that high math anxious individuals performed poorly in comparison to low math anxious individuals, it was not clear whether this was due to the math anxiety specifically or to inefficiency in inhibiting attention based on the thoughts provoked by other factors such as distractibility.

To examine if indeed math anxiety consumed working memory resources, Ashcraft and Kirk (2001) introduced a dual task paradigm in their experiment. If math anxiety and performance of the math task were competing for working memory resources, the dual task paradigm would be sure to show it. The authors' prediction was that there would be a competition for working memory resources, and, in fact, that is what was found; those participants with the highest levels of math anxiety had the poorest performance on the math task. This was especially the case on carry problems, those previously shown to rely heavily on working memory. Therefore, it seems that math anxiety can consume working memory resources.

Current experiment

Previous literature has mainly focused on a "declarative memory" approach (testing participants on what they already know) to the study of math anxiety. The literature has not yet examined learning in the context of math anxiety, which seems odd, given that, in general we believe that math anxious individuals learn less math in school. This inference is drawn from evidence concerning math achievement tests; math anxious individuals tend to score lower on these tests than non-math anxious individuals. As an initial attempt to examine learning in the context of math anxiety, the standard true/false verification task was used with college students, where the construction of the stimulus set provided differential opportunities for learning to take place. In particular, one set of stimuli was repeated nine times throughout the experiment, providing multiple opportunities for learning, whereas the other set of stimuli was only shown once. Because adults already know the answers to simple addition facts, the learning being examined here involved "stimulus learning," in other words, learning that, for example, the incorrect answer 17 appeared with the problem 7 + 8. Collecting RT and error data across three blocks of trials afforded a substantial body of data with which to address issues related to learning on the part of low vs. high math anxious participants; (e.g., examination of performance improvement across practice for repeated vs. non-repeated problems as a function of math anxiety and split). Beyond this, participants in the intentional learning condition were told at the outset that they would be asked to recall the answers they saw during the experimental trials, so they were expected to attempt to encode and remember these numbers. They were predicted to be more accurate in doing so for answers that repeat nine times. Comparing performance, both in the timed experimental trials and on the memory task as a function of math anxiety, problem size, split, and working memory, provided new insights into the role of math anxiety as individuals perform a demanding and memory-dependent mathematical cognition task.

The current study was aimed at examining math anxiety and its effects on the storage of arithmetic information. These effects were investigated in terms of how well participants would be able to remember information about simple addition problems, depending on their level of math anxiety. Problems were presented for true/false verification, with half of the problems presented with a correct answer of true and half with a false answer. In past research (e.g. Ashcraft & Bataglia, 1978), false problems have been categorized as being reasonable false or unreasonable false problems. For the 1978 study, Ashcraft and Bataglia used splits of ±1 or 2 for reasonable false problems, and ±5 or 6 to designate unreasonable false problems. Reaction times were found to be faster for unreasonable false problems. When participants saw a false problem, they may or may not have remembered the wrong answer that was paired with the problem. Whether or not they remembered may have been due to the size of the split and/or the level of math anxiety. The current experiment utilized three levels of split, ±1 or 2, ±5 or 6, and ±8 or 9, small, medium, and large, respectively.

Consistent with previous findings, one prediction was that, demographically, high math anxious individuals would have taken less high school and college math courses and received lower grades in them on average than the low math anxious individuals.

Another result expected to be consistent with the literature was that high math anxious participants with high working memory capacity would still be less accurate than the low math anxious participants due to the math anxiety competing for working memory resources needed to complete the task.

A final prediction was that participants in the intentional learning condition would outperform those in the incidental learning condition on the memory task, regardless of math anxiety. The effects of repetition on stimulus learning might have revealed the effects of math anxiety in the incidental learning condition such that low math anxious participants may have shown superior memory for the answers because their working memory was less burdened during math performance, hence their free working memory resources would be better able to encode this information. Along the same lines, high math anxious participants would have fewer working memory resources available during processing, so would be expected to encode and remember less of the information about the false answers. It was possible, however, that a result in the opposite direction might be obtained. That is, high math anxious individuals may have actually spent additional time in processing false problems, especially those with large splits; after all, Faust et al. (1996) found high math anxious individuals to make more errors, rather than fewer, when addition problems had larger splits. Thus, paradoxically, because of additional processing time, high math anxious participants might have actually demonstrated better memory for the false answers with large splits, due to longer exposure to those answers.

Overall the results were predicted to show that not only was the high math anxiety interfering with the processes of working memory and the ability to perform simple calculations, but that it was also interfering with the learning of basic math fact.

CHAPTER 3

METHODOLOGY

Participants

Participants were recruited from the UNLV subject pool. 73 students participated in the experiment to receive course credit.

Materials

Demographic information was collected from all participants using a computer-based survey. Basic demographic information such as age, ethnicity, and year in school was obtained, and there was also information obtained that was specific to this experiment. This information included the number of high school math courses taken, the average grade they received in their high school math courses, the average grade they received in their college math courses, how much they enjoyed math, and how math anxious they considered themselves to be. There was also a checklist on the sheet so they could check all of the types of math classes that they had taken either in high school or while attending UNLV.

Short Mathematics Anxiety Rating Scale (sMARS). The sMARS was administered to all participants to determine their individual level of math anxiety. It is a 25-item questionnaire containing items that ask about specific math situations encountered in the classroom (taking a pop quiz) as well as those math situations encountered in everyday life (calculating a tip in a restaurant). The questionnaire was completed on the computer. Previous research has found the grand mean on the sMARS to be 36 with a standard deviation of 16 (Ashcraft, et al., 2007).

Operation Span (OSPAN): Self-Paced. This task was based off of the original OSPAN task designed by Turner and Engle in 1989. The self paced version of the OSPAN was used in the current experiment to give an estimate of participants' working memory spans. The OSPAN required the participant to read math equations and then verify whether or not the answer presented was true or false; the equation remained on the screen until the participant pressed one of the required mouse buttons. After each equation, a word was presented on the screen for 250ms (different words will follow each equation). Following anywhere from two to six equation-word combinations, the participant was asked to type in the words that were presented to them in the same order that they saw them; a text box appeared on the screen for the participants to type in the words. The task was completed on the computer; the participants used the mouse to verify the equations as true or false, pressing the left mouse button for true and the right mouse button for false, and the keyboard to type in the words. The task was completed once the participant was given three trials of each set size two through six, regardless of accuracy on the equation verification or word lists. There were two practice trials for the participants to get accustomed to the task.

Experimental Stimuli

The experimental stimuli consisted of three blocks with 48 problems in each block. The stimuli were constructed from the 56 possible nontie, pairwise combinations of the integers 2-9. One and zero were not used as addends because it is generally conceded in the literature that participants tend to use rules instead of direct retrieval for problems involving one and zero addends. The frequency and placement of all integers was random. Exact repetition of a problem across trials was permitted in the sense that the same problem could have been randomly selected two times in a row from the stimuli since 12 of the stimuli repeated 3 times throughout the set. This was not deemed to pose a problem because the answers to the basic facts are already assumed to be stored in long term memory. The literature has demonstrated that retrieval of answers to these problems is done based on a network retrieval model; therefore, although repetition priming was expected to create a faster reaction time, the difference was not expected to be significant.

Procedure

Upon arrival to the laboratory, the participant completed a consent form, the demographic survey, and the sMARS. The experimenter went through the instructions thoroughly and ran the participants through the OSPAN on the computer. The participant was randomly pre-assigned to either an incidental or an intentional learning condition. Instructions were given to the participants, explaining to them the task they were about to perform and how to use the equipment provided to complete the task. Participants assigned to the intentional learning condition were also told at this time that there would be a later task in which they would be tested on how many answers they could remember from the problems given during the task. All participants were then given a practice block and three experimental blocks of simple addition problems. The practice block contained 8 trials to get the participant accustomed to using the mouse for verification; the left button was pushed for true and the right button for false. Each experimental block contained 48 problems, with answers, and the participants had to answer true/false by depressing one of two buttons on the mouse to indicate their response. Half of the problems per experimental block were true and half false, 24 problems each. As far as problem size was concerned, addition problems with a sum of 10 or less were considered small and those with a sum of more than 10 were considered large. There were 24 large and 24 small problems per experimental block of trials. The problems were also evenly divided among split so that small, medium, and large splits were represented by 16 problems each per block of trials. Small splits for this experiment were ±1, ±2 away from the correct sum, medium splits were ±5, ±6 away from the correct sum, and large splits were ±8, ±9 away from the correct sum. Also, half of the problems per block, 12 problems, repeated three times each through all three experimental blocks, so over the three experimental blocks, the participant saw some problems only once and some problems nine times. After completion of the last experimental block of trials, a prompted recall test was given to the participants. The prompted recall test was also administered on the computer. A problem stem, with a blank space following the equals sign, was presented on the screen along with a text box for participants to enter their responses. Participants were asked to try and recall the false answer that was presented with the problem during the experiment.

Statistical Analyses

For all problems, a 3 x 3 x 2 x 2 x 2 x 2 analysis of variance was conducted using SPSS software. Factors examined included math anxiety, split, problem size, incidental vs. intentional learning, true/false, and repeat/no repeat, respectively. Math anxiety and incidental vs. intentional were between subjects variables and the rest were within subjects variables. Three dependent variables were analyzed: errors, reaction times, and stimulus learning, which was calculated based on the number of false answers correctly recalled on the prompted recall test.

Error rates of 15% or higher indicated an unusual amount of incorrect answers to problems, which could mean that the participants ignored the purpose of the experiment and simply tried to get through as fast as they could or that the participant was exceptionally below average in terms of arithmetic ability. Because of this, it was decided that participants not achieving an accuracy rate of at least 85% on the experimental task would not be included in the data analyses for the study. Error rates were examined to see if any of the participants were not able to meet the accuracy criteria; all participants in the study did achieve at least 85% accuracy for the problems in the experimental task. Therefore, no participants were excluded from the analyses for not meeting the above criteria.

Also examined were math anxiety level, working memory capacity, and how those two related to error rates for false problems. Descriptive statistics and Chi-square were used to review demographics to look at the number of math classes taken and grades received along with self-reports of math anxiety and math enjoyment and how those related to the level of math anxiety that the participant exhibited.

CHAPTER 4

DATA ANALYSIS AND RESULTS

The major design used in this experiment was a repeated measures mixed model factorial. Within subjects factors included block, split, problem size, repeat, and true/false while between subjects factors consisted of math anxiety, memory span group, and learning condition. A short description of three of the above variables will be given to maintain clarity with respect to the design.

Participants were randomly assigned to either of two learning conditions. One was an intentional learning condition; for this condition, the experimenter stressed to the participants that there would be a recall task following the experimental task, and that they would be asked to recall answers that had been presented with the problems when they saw them. The second learning condition was an incidental learning condition in which the participant was told nothing regarding the recall task before beginning the experimental trials. For the recall task, participants were shown a problem stem and required to supply the false answer that was displayed with that stem when they saw it during the experiment; answers to true problems were not requested since these could be answered based on the participants' knowledge of arithmetic.

The repeat factor consisted of a manipulation of problem repetition throughout the three blocks. The participants saw each of twelve problems repeat three times per block. Thus, after three blocks of trials, participants saw those twelve repeated problems a total of nine times. Participants were also presented in each block with twelve problems that were unique, that is, problems that appeared only one time. Participants saw unique problems only once throughout the three blocks of trials versus nine times each for repeated problems.

For the factor split, which only pertained to the false stimuli, there were three different categories: problems with answers that differed from the true answer by ±1 or 2(small splits), ±5 or 6(medium splits), and ±8 or 9(large splits). In each of three blocks, there were forty-eight trials. In a forty-eight trial block, the participants saw six repeated false problems and six unique false problems, with two false problems in each group having small, medium, or large splits.

Results on the demographic characteristics will be given in this section as well as a discussion of reaction time and error rate data for both the true and false problems in the experiment. Concerning error rate data, working memory span results will be discussed in relation to error rates on false problems, and finally, recall performance of the participants will be discussed.

Demographics

Seventy-three undergraduate students (age range: 18-67, with a mean of 20.91) consented to participate in the experiment for course credit. Nine participants did not follow instructions on the recall task. The recall task was forced, i.e. they were required to provide an answer for the problem stem presented regardless of whether they thought they knew the answer; however, nine participants left several answers blank or indicated "don't know" for the answer. Data for those nine participants was excluded from analysis, leaving sixty-four subjects whose data were included in the analyses. Means for several demographic variables are displayed in Table 1. Twenty six men and thirty eight women were randomly assigned to either the intentional or incidental learning condition. Participants were grouped by their sMARS scores into math anxiety groups; however, this was not done in the usual way. In the past, participants were eliminated if they did not clearly fall into one of the three math anxiety groups i.e. elimination occurred if participants fell within one standard deviation above or below the sMARS mean of 36. After examining the demographic data for the current study, it was found that 6 participants fell within one standard deviation below the mean and 6 participants fell within one standard deviation above the mean. Not only that, but the math anxiety groups were fairly uneven in terms of sample size (low math anxiety n = 13, medium math anxiety n = 23, and high math anxiety n = 16). Therefore, the 6 participants below the mean were put into the low math anxiety group and the 6 participants above the mean were put into the high math group, creating the following: low math anxiety n = 19, medium math anxiety n = 23, and high math anxiety n = 22. In order to make sure the groups were still significantly separated according to their sMARS scores, a one-way ANOVA was conducted F(2, 64) = 165.718 p = .000.

In terms of math anxiety, the percentage of participants did not differ by gender, $\chi^2(2, n = 64) = 3.382, p = .184$ nor by ethnic group, $\chi^2(10, n = 64) = 11.586, p = .314$. Self-report ratings of both math anxiety and math enjoyment were found to be significant among math anxiety groups F(2, 61) = 7.613 p = .001, $\eta_p^2 = .200$ and F(2, 61) = 5.895 p = .005, $\eta_p^2 = .162$, respectively. High math anxious participants self-reported having higher math anxiety and lower math enjoyment, and the opposite pattern was found for low math anxious participants. The only significant result regarding gender was found with regard to self reports of math anxiety $F(1, 62) = 5.143$ $p = .027$, $\eta_p^2 = .077$, with women self-reporting being more math anxious than men.

Participants did not differ significantly with respect to high school math grades, regardless of math anxiety group $F(2, 60) = 2.306$ $p = .108$ η_p^2; however for the participants that reported an average grade for their college math courses (n = 34), results yielded significantly lower grades being reported for participants with high levels of math anxiety compared to participants with low levels of math anxiety $F(2, 31) = 4.074$ $p = .027$, $\eta_p^2 = .208$. This difference may be due to high school math standards being less stringent than college math standards. As a result students might have an easier time achieving higher grades in high school, regardless of their math anxiety level.

Reaction Time Data (Experimental Task)

A 3 x 3 x 3 x 2 x 2 x 2 x 2 repeated measures ANOVA was used for both reaction time data and error rate data. Within subjects factors consisted of block, split, problem size, repeat, and true/false while between subjects factors consisted of math anxiety, and learning condition.

Outliers were defined as reaction times that fell more than two and a half standard deviations above or below the mean. None of the reaction time data fit the criteria of being an outlier. This was probably due to the simplicity of the arithmetic stimuli; therefore, no reaction times were removed, and no methods of outlier replacement were used.

True and False Problem Commonalities

For both true and false problems there was a significant main effect of learning condition (true, $F(1, 58) = 18.937$ $p = .000$, $\eta_p^2 = .246$; false, $F(1, 58) = 18.406$ $p = .000$, $\eta_p^2 = .241$) on reaction times. Participants in the intentional learning condition took an average of over 600 ms longer to verify the problem as true or false than participants in the incidental learning condition. One way to explain this difference is by looking at the difference in the instructions given to participants in the intentional learning condition. It was heavily stressed to the participants in the intentional learning condition that there would be a recall task following the verification task, and that they would need to remember some of the answers that were presented with the problems that they were about to see. With that in mind, the significant difference in reaction times between learning conditions can be accounted for.

With regard to the within subjects variables, there were significant main effects for block and problem size and several interaction effects. As expected, there was a significant speed-up in reaction times across blocks (true, $F(2, 116) = 76.761$ $p = .000$, $\eta_p^2 = .570$; false, $F(2, 116) = 62.831$ $p = .000$, $\eta_p^2 = .520$). Significant reaction time differences were also found with regard to problem size (true, $F(1, 58) = 134.111$ $p = .000$, $\eta_p^2 = .698$; false, $F(1, 58) = 50.479$ $p = .000$, $\eta_p^2 = .465$) in that large problems took an average of over 500 ms longer to verify than small problems. The problem size effect has been explained in terms of a counting model (Groen & Parkman, 1972), a network retrieval model (Ashcraft & Battaglia, 1978), and also by a possible lack of experience with large problems from a very early grade level (Hamann & Ashcraft, 1986). For a thorough review of the literature on the problem size effect see Zbrodoff & Logan (2005).

Several significant interaction effects for reaction times were found to be consistent between true and false problems. There was a significant block x learning condition interaction (true, $F(2, 116) = 4.937$ $p = .009$, $\eta_p^2 = .078$; false, $F(2, 116) = 12.250$ $p = .000$, $\eta_p^2 = .174$) such that participants sped up across blocks independent of learning condition; however, participants in the intentional condition were slower overall than participants in the incidental learning condition, especially in block 1. This interaction is illustrated in figures 1 & 2.

A significant block x problem size interaction was also found for both true and false problems (true, $F(2, 116) = 15.105$ $p = .000$, $\eta_p^2 = .207$; false, $F(2, 116) = 4.739$ $p = .011$, $\eta_p^2 = .076$). There was a general decrease in reaction times across blocks; however, large problems took significantly longer across all three blocks. In block one, participants took an average of 700 ms longer to verify large problems than small problems; however, by block three, this average went down so that participants were only taking an average of 300 ms longer to verify large problems than small problems. This interaction provides further illustration of the problem size effect as well as practice and priming effects that have been found throughout the literature (Ashcraft & Bataglia, 1978; Ashcraft & Stazyk, 1981).

Although there was no main effect for math anxiety, both true and false problems showed a significant or nearly significant problem size x math anxiety interaction (true, $F(2, 58) = 3.041$ $p = .055$, $\eta_p^2 = .095$; false, $F(2, 58) = 3.430$ $p = .039$, $\eta_p^2 = .106$). In figures 3 & 4, the medium and high math anxious groups showed the general pattern of slower reaction times for larger problems; however, both groups were significantly slower than the low math anxious group for both small and large problems. Even though the high math anxious group was slower than the medium math anxious group overall, the difference was not significant, and the two groups really appeared to cluster together and separate from the low anxiety group. This is something to consider in terms of how math anxiety groups are determined, and will be examined further in the discussion section.

True Problems

One interaction effect that was not found with false problems regarding reaction time was that even though there was no main effect of repeat, there was a significant block x repeat interaction $F(2, 116) = 12.127$ $p = .000$, $\eta_p^2 = .173$. As figure 5 illustrates, repeated problems sped up across blocks faster than no-repeat problems. This was also not surprising because as participants were going through the verification task, they saw the same repeated problems three times in each block. By the end of the third block, participants had seen repeated problems nine times.

False Problems

The false problems contained the extra factor of split, which resulted in several significant interaction effects that differed from the true problems. There were significant effects of split $F(2, 116) = 23.563$ $p = .000$, $\eta_p^2 = .289$ and repeat $F(1, 58) = 31.103$ $p = .000$, $\eta_p^2 = .349$. Displayed in figure 6 are the average reaction times per split group. Reaction time was the slowest for splits of ±1, 2, continuously sped up through splits of ±5, 6, and reached the fastest verification times for splits of ±8, 9. False problems were harder to verify as false when the answer given differed by a small amount. This result is consistent with past literature (e.g., Ashcraft & Bataglia, 1978, Ashcraft & Stazyk, 1981). It seems that when the false answer is close to the true answer, more second-guessing takes place whereas when the answer provided is very different from the true answer, it is easier to disregard it as false. Ashcraft and Stazyk (1981) discussed this in terms of a "ballpark" decision process i.e. if the split is large, the value is so unreasonable, so "out of the ballpark," that participants can reject the problem quickly, an explanation that seems to capture the pattern shown here.

Error Rate Data (Experimental Task)

For this experiment, an error was considered to be incorrectly verifying either a false problem as true or a true problem as false during the experimental trials. Error rates were computed for each participant in each condition.

True Problems

There was only one significant finding with regard to true problems and error rates, and that was a significant main effect of problem size $F(1, 58) = 8.854$ $p = .004$, $\eta_p^2 = .132$. On average, participants made 2% errors on small problems and 4% errors on large problems. This finding is once again consistent with the problem size effect observed in the literature as well as a possible lower degree of practice with large problems overall. None of the other within subjects factors or interactions were significant and neither of the between subjects factors, learning condition or math anxiety, approached significance $F(1, 58) = .004$ $p = .949$, $F(2, 58) = .203$ $p = .817$, respectively.

False Problems

False problems provided several significant effects worth noting. There were found to be significant main effects for problem size, split, and repeat; $F(1, 58) = 8.178$ $p = .006$, $\eta_p^2 = .124$, $F(2, 116) = 19.803$ $p = .000$, $\eta_p^2 = .255$, and $F(1, 116) = 11.079$ $p = .002$, $\eta_p^2 = .160$, respectively. Participants made five percent errors on false problems with small splits compared with only one percent errors for false problems with medium or large splits. Once again, this illustrates that it is more difficult for participants to judge problems with small splits as incorrect than to judge problems with large splits as incorrect. Errors made on large false problems were similar to errors made for large true problems and were one percent higher than the error rate for small false problems. The significant main effect of repeat was not unexpected; however, prior to conducting the experiment, it was thought that more errors would be made on no-repeat problems. Exactly the opposite effect was found; the percentage of errors made for repeated problems was twice that of unique problems for high math anxious participants, $F(1, 58) = 11.079$ $p = .002$, $\eta_p^2 = .160$.

Along with the main effects mentioned above, all two and three-way interaction combinations of split, repeat, and problem size were significant. The trend for each followed the same patterns as the main effects with more errors being made on large, repeated problems with small splits. The three-way interaction is displayed in figures 7 and 8, $F(3, 116) = 7.356$ $p = .001$, $\eta_p^2 = .113$.

Another significant three-way interaction was found that included math anxiety. Shown in figures 9 and 10 is the significant split x repeat x math anxiety interaction $F(3, 116) = 2.945$ $p = .023$, $\eta_p^2 = .092$. For the unique problems, all three math anxiety groups performed similarly in terms of error percentages, ranging from zero to four percent, with the four percent error rate being found for high math anxious individuals verifying unique problems with small splits. The much more interesting finding comes from looking at the repeated problems. Again, for the medium and high splits, the math anxiety groups pretty much cluster together with respect to percent errors; however, error rates jump dramatically among the groups when it comes to repeated problems with small splits. The low math anxious group made four percent errors, the medium math anxious group made twelve percent errors (three times that of the low math anxious group), and the high math anxious group made seven percent errors. The medium and high math anxious individuals really seemed to be second-guessing themselves after seeing a false problem with a small split several times.

The above results provide the opportunity for some investigative applications of previous theories. For example, the results may be due to a familiarity effect (Atkinson & Juola, 1973) for simple addition problems that changes for high math anxious individuals. The more times the problem is shown, the more familiar the false answer becomes. As a result, high math anxious participants become less sure that they are verifying correctly, and therefore are likely to make errors. This explanation will be considered in greater detail in the discussion section.

Operation Span (OSPAN): Reaction Times and Error Rates

The OSPAN was given to participants to measure their working memory capacities. Participants were separated into high and low span by performing a median split on participants' raw scores obtained by the OSPAN. The distribution of high and low span participants among the math anxiety groups can be seen in table 1. To be thorough, a Chi-square test was performed to make sure the percentages of high and low span participants were not significantly different among the math anxiety groups, $\chi^2(2, n = 64) = 1.110, p = .574$. To investigate any effects of working memory span on the data, span group was inserted as a between subjects variable into the repeated measures ANOVA to examine reaction times and error rates. Even though true and false problems were analyzed, false problems were of special interest, since recall results consisting of only false problems were used to measure stimulus learning in the current study.

Reaction Times (true and false problems)

Reaction time analysis for true problems showed two significant three-way interactions involving working memory span. The first was a repeat x span group x math anxiety group interaction, $F(2, 58) = 3.422$ $p = .039$. Shown in figures 11 & 12, reaction times were pretty stable across repeat condition except for in the high span group, figure 12, where the medium and high math anxious participants switched places from the repeated to the unique condition. Overall, low math anxious participants took less time to verify answers to true problems regardless of span group; however, low math anxious participants with low working memory spans took an average of around 250 ms longer to verify than low math anxious participants with high working memory spans. This seems to indicate a general slowing down of reaction times due solely to working memory span differences; low working memory span may result in being more easily distracted from the task (mind wandering from the task at hand resulting in longer reaction times). Also significant, displayed in figures 13 & 14, was the block x problem size x span group interaction F(2, 116) = 3.526 p = .033. This result was not surprising: reaction times to true problems were longer for large problems (problem-size effect), longer for low span participants, and shorter across blocks (practice effect). No Significant results were obtained regarding working memory span and reaction times to false problems.

Error Rates (true and false problems)

Error rate analysis for true problems resulted in one main effect approaching significance, span group F(1, 58) = 3.766 p = .057, figure 15, and one significant interaction, repeat x span group F(1, 58) = 5.672 p =.021, figure 16. Even though these effects were significant, the error rates were very small. For example, the low span participants had a 3% error rate while the high span participants had a 1% error rate, see figure 15. For true problems, high span participants still made more errors on repeated trials. Low span participants made more errors on unique trials, which is opposite of the general trend for error rates mentioned above; however, the difference in error rates from repeated to unique trials was not even 2%. Several significant results were also obtained when working memory span and error rates to false problems were studied. Low span participants made more than twice as many errors, 5% compared to 2% for high span participants, on false problems, especially large problems. Figure 17 displays the significant problem size x span group interaction, F(1, 58) = 4.520 p = .038, η_p^2 = .072. Seyler, Kirk, and Ashcraft (2003) found a similar interaction effect with regard to subtraction problems. In their subtraction only condition; low span participants were found to have made 12.5% and 16.2% errors on small and large problems, respectively. According to the results of the current study, that pattern continues across simple addition problems as well, giving further evidence to the idea that large problems depend more heavily on working memory resources.

Furthermore, when split was taken into consideration, a significant split x problem size x span group interaction was found, $F(2, 116) = 4.534$ $p = .013$, $\eta_p^2 = .072$), such that low span participants, compared to high span participants, made more errors on large problems with small splits, 12% and 6%, respectively. This interaction effect was consistent with literature regarding the split effect; the closer the split answer is to the true answer, the harder it is for participants to verify the problem as false, an effect that is especially true for low span participants. Less than 2% errors were made by either high or low span participants on false problems having medium or large splits, see figures 18 & 19.

High span participants made fewer errors on false problems regardless of math anxiety group; however, low span participants, especially those with medium and high math anxiety, made significantly more errors, 12% and 6%, respectively, than those low span participants with low math anxiety, 2%, figure 18. The three-way interaction of split x math anxiety x span_group, figures 20 & 21, was highly significant, $F(4, 116) = 3.805$ $p = .006$, $\eta_p^2 = .116$. This result lends further support to the theory that math anxiety takes up valuable working memory resources needed to correctly complete a math task (Ashcraft & Faust, 1994; Ashcraft & Kirk, 2001).

Consistent with error rate results above for false problems, more errors were made on false problems that repeated than false problems that were unique, especially for those participants who were higher in math anxiety and classified as low span. Significant results were found for the following two- and three-way interactions: repeat x span group

$F(1, 58) = 6.873$ $p = .011$, $\eta_p^2 = .106$ and repeat x math anxiety group x span group $F(2, 58) = 5.360$ $p = .007$, $\eta_p^2 = .156$. The highest error percentage, 9%, was made by those individuals who were low span and had a medium level of math anxiety. Figures 22 & 23 illustrate this result nicely.

Other significant interaction effects found for false problems and error rates that further illustrate the above points included the following:, split x repeat x span group $F(2, 116) = 3.069$ $p = .05$, $\eta_p^2 = .050$, block x split x math anxiety group x span group $F(8, 232) = 2.033$ $p = .044$, $\eta_p^2 = .065$, split x problem size x math anxiety group x span group $F(4, 116) = 3.415$ $p = .011$, $\eta_p^2 = .105$, split x repeat x math anxiety group x span group $F(4, 116) = 5.104$ $p = .001$, $\eta_p^2 = .150$, and problem size x repeat x math anxiety group x span group $F(2, 58) = 4.563$ $p = .014$, $\eta_p^2 = .136$. In general, these results are indicative of the problem size and split effects. More errors were typically made when verifying large problems and problems with small splits. Also, with exception to true stimuli, which were not as highly considered as the false stimuli due to the nature of the experiment and the forced recall task, more errors were made when verifying repeated stimuli than unique stimuli. This particular pattern provides for some interesting theoretical implications that will be examined in the discussion section. All of the above significant interactions illustrated that low span individuals spent more time on and made more errors when verifying answers to simple addition stimuli. The results also indicate a tendency for math anxiety to have more of an effect on low working memory span individuals than high working memory span individuals. A possible theoretical connection between math anxiety and working memory span will also be examined in the discussion section.

Forced Recall Task

Learning, as measured by recall accuracy, was examined using a 3 x 3 x 2 x 2 x 2 mixed model ANOVA examining the factors of split, math anxiety, problem size, repeat, and learning condition respectively. There were significant main effects of split $F(2, 116) = 47.205$ $p = .000$, $\eta_p^2 = .449$ and repeat $F(1, 59) = 83.398$ $p = .000$, $\eta_p^2 = .590$. There was also a significant split by repeat interaction, $F(2, 116) = 28.461$, $p = .000$, $\eta_p^2 = .329$. As shown in figure 24 (split x repeat), significant recall differences were found for repeated problems with either low or medium size splits; however, whether the problem was repeated or not, recall efforts were poor for problems with large splits. Note that this is not a simple function of how long the problems were processed during the verification phase of the experiment. Small split problems took longer to reject, to be sure, and therefore might be expected to be recalled better, and likewise, large split problems took less time to reject, hence might be expected to be recalled more poorly. But medium split problems were also rejected fairly rapidly (Figure 6), yet were recalled nearly as well as small split answers; at least that was the case for high and medium math anxious participants. The resolution of this paradox is found in Figures 25 & 26, depicting the significant interaction of repeat x split x math anxiety.

Although there was no main effect for math anxiety $F(1, 58) = 2.136$ $p = .127$, there was a significant repeat x split x math anxiety interaction $F(4, 116) = 3.298$ $p = .013$, $\eta_p^2 = .102$. The interaction can be seen in figures 25 & 26, with figure 25 displaying the problems that did repeat and figure 26 displaying the problems that did not repeat. As shown in figure 26, unique problems showed little difference among math anxiety groups with regard to recall accuracy, except for the general trend of recalling more answers with small splits than with medium or large splits. However, for the repeated problems, there were differences among the math anxiety groups and their recall of false answers such that low math anxious participants recalled less than the high math anxious participants for repeated problems with small splits. Also, for repeated problems with medium splits, the low math anxious group recalled less than both the medium and the high math anxious groups. This finding could possibly be the result of the low math anxious participants spending less time looking at the problems. It may have been easier for the low math anxious group to reject a problem as false, whereas a medium or high math anxious participant might have spent longer looking at the problem, figuring out what the answer was, deciding if the answer provided with the problem matched and then possibly even double checking to make sure.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Hypotheses

The first hypothesis of the current study involved the demographic information. It was expected that high math anxious participants would have taken fewer high school and college math courses and received lower grades in the math classes that they had taken. Analyses did not indicate any significant differences among the math anxiety groups and how many math classes they had taken in high school or college or the average grades received in high school math courses. This simply could have been a result of having too small a sample size. Another possibility that might be specific to the school district in which the study took place, is that local high school requirements and grading standards may be more lenient in terms of achieving grades. It may have also been helpful to collect data concerning specific college major requirements for how many math courses individual participants needed for graduation. The demographic sheet used in the current study did not include a place for participants to indicate their current college majors. Significant differences were found, however, with regard to the average grades received in participants' college math courses. As mentioned in the results section, low math anxious participants did report earning significantly higher grades in their college math courses than high math anxious participants. What could account for there being no significant differences among math anxiety groups and high school math grades, but then there being a significant difference with regard to their college math grades? It is certainly a possibility that high math anxious students may not be ready, in general, for the demands of college math courses, especially if the standards for high school grading were not as stringent; in fact, the high math anxiety may even interfere with their ability to adapt to learning new math tasks which are possibly being taught at a faster and more demanding rate than before. On the other hand low math anxious students may have a greater ability to adapt to increasing standards because they would have little, if any, anxiety about the new math tasks at hand.

A second hypothesis of the current study was that participants in the intentional learning condition would have higher recall accuracy than those participants in the incidental learning condition, and that this result would occur regardless of math anxiety. This hypothesis was not confirmed. Even though participants in the intentional learning condition spent significantly longer looking at the simple addition stimuli (refer back to figures 1 & 2), learning condition was not found to have any significant effects on recall accuracy. However, math anxiety was found to be a significant factor affecting recall accuracy, but not in the way that the current study would have predicted prior to running participants. These results will be discussed in detail in the next section along with results concerning the final hypothesis of the experiment, which posited that participants with high math anxiety and high working memory capacity would still be less accurate on the recall task than the low math anxious participants with either high or low working memory capacities.

Added Findings and Possible Explanations

Two unexpected findings occurred during this experiment in that the high math anxious participants both made more errors on repeated problems and yet correctly recalled more false answers with both small and medium splits than did low math anxious participants. In order to make sense of these results, it may be possible to apply an established model for recognition, with a few minor changes. In a 1973 chapter, Atkinson and Juola refer to a specific model of recognition for well-learned lists of words. According to the model, as soon as participants see the test stimulus, they do one of two things: they can make a judgment based on their already existing familiarity value for the word, or they can delay their response until after an extensive memory search has been made.

The model predicts a "fast yes" or a "fast no" response if the participant's familiarity value exceeds or is below certain thresholds; however, if the familiarity value is in between those two thresholds, then an extensive search of memory takes place, and the latencies get longer as a result (Atkinson & Juola, 1973). This model can readily be applied to the simple addition verification task used in this experiment. For college students, simple addition facts could be likened to a well-learned list where the answers are already in long term memory and are pulled out using a network retrieval model (Ashcraft & Battaglia, 1978). Applying the Atkinson and Juola model, if the test stimulus presented was a true problem, the participant's familiarity value would have been expected to be very high, resulting in a "fast yes" response. On the other hand, if the test stimulus presented was a false problem, the participant's familiarity value would be very low, resulting in a "fast no" response. The second part of the model did not hold true for participants with varying levels of math anxiety. Although both high and low math anxious participants were faster overall for repeated problems than for unique problems, the high math anxious participants were much slower than the low math anxious participants to verify both repeated and unique false problems across all levels of split. It is possible that the familiarity value of high math anxious participants for false problems started to fall in between the two thresholds as the problem repeated, resulting in a more extensive memory search to double check the answer. In other words, the high math anxious participants possibly began to second guess themselves as the false problem repeated i.e. the false problem actually developed its own familiarity value with repeated viewings, but only for high math anxious participants who may have not been as confident in their retrieved answer in the first place. This could explain the higher error rate exhibited by high math anxious participants for false repeated problems; as the familiarity value increased, high math anxious individuals were more likely to verify the false problem as true. Also, since high math anxious participants spent more time overall looking at repeated problems at all levels of split, it was more likely that the false answer paired with a particular problem would be encoded into short term memory and remembered during the recall task, especially for small and medium splits.

These results also lend further support to the network-interference model of retrieval (Campbell, 1987a; Campbell, 1987b). Assumptions of this model are that arithmetic problems access a shared network of possible answers, and that related problems activate overlapping areas of the network. According to the model, an encoded problem has a set of potential responses activated in memory, and the speed and probability of retrieval is a function of activation level of the correct answer, relative to competing answers in the overlapping area (Campbell, 1990). Results from the current experiment supporting this model were that all participants, regardless of math anxiety level, were slower and made more errors on false problems with small splits; these results illustrate that answers that are close to the correct answer overlap with the correct answer in the network, and that both speed and accuracy depend on the activation level of the correct answer relative to other answers in the network.

It is possible to tie in the network-interference model with the above idea of high math anxious individuals developing an increased familiarity value for repeated false problems. Results for the current experiment pointed to an increasing familiarity value for repeated false problems, especially for high math anxious participants. Drawing from the network-interference model, it can also be concluded that the false answer was gaining a higher level of activation with each repetition. As the false problems repeated throughout the experiment, assume that both the familiarity level and the level of activation became higher for the presented false answer than for the true answer. The previously presented false answer was not only more familiar, but also was activated first, interfering with the activation level of and the ability to retrieve the true answer. Therefore a greater likelihood was that participants, especially those with higher levels of math anxiety, would answer true instead of false to the repeated false problems. On the other hand, the results suggest that low math anxious individuals have such a high level of activation for the true answer already, possibly resulting from a combination of more practice, more confidence, and less anxiety, that, even with increased activation and familiarity for the answers to repeated false problems, it was still easier for them to reject the answer presented and correctly verify the problem as false.

The working memory data collected from the current study also produced results worth discussing. Recall from above, that the final hypothesis of the current experiment was that high math anxious participants with high working memory spans would be less accurate on the verification task than low math anxious participants. This hypothesis was derived from previous evidence that math anxiety interferes with working memory resources needed to complete a math task (Ashcraft & Kirk, 2001). Results from the current experiment did not confirm this hypothesis, although one reason for this could have been the stimuli used for the study. College students, who can be expected to be heavily practiced on simple addition problems, are unlikely to make many verification errors on simple addition stimuli. Significant error rate results in Ashcraft and Kirk (2001) were found for large problems involving a carrying operation. Results from the current experiment might have been consistent with Ashcraft and Kirk (2002) had the stimuli been more challenging for the participants. Even though the hypothesis was unconfirmed, there were other working memory span results of interest. In particular, low span participants with higher levels of math anxiety made more errors on repeated false problems with small splits, see figures 14 and 15. Familiarity effects have already been discussed with regard to higher levels of math anxiety, but it is also possible that having a low working memory span, i.e. not being able to sufficiently hold and process a lot of information at once, creates susceptibility to developing an increased familiarity to repeated problems. As mentioned above, this increased familiarity effect could account for participants, especially those with low working memory spans and high math anxiety, more likely verifying a false problems as true the more times that they see it.

General Conclusions

In the past, it has been shown that math anxiety interferes not only with performing math tasks (Ashcraft & Faust, 1994; Ashcraft & Kirk, 1998; Faust, Ashcraft, & Fleck, 1996), but also with working memory resources (Ashcraft & Kirk, 2001; Hopko, Ashcraft, & Gute, 1998). The current study examined both math anxiety and working memory capacity in the context of stimulus learning. High math anxious participants were found to be able to learn more of the stimuli; however, this was not due to efficiency in verification. Results indicated that higher stimulus learning rates from high math anxious participants were more likely due to more time spent looking at the problems before verification. It has been theorized above that high math anxious participants may have more interference and activation for several answers surrounding the correct answer. This was indicated in results showing high math anxious participants making more verification errors, especially to repeated problems, but still being able to correctly recall significantly more false answers correctly, especially for false problems with small splits, where the false answer was only one or two away from the true answer. Higher stimulus learning rates in the current study actually indicated that high math anxious individuals may have a less efficient network retrieval model consisting of more interference along with a susceptibility to develop an increased familiarity rate to repeated false stimuli.

In general, it seems that high math anxious individuals with low working memory spans are more susceptible to making errors. In the case of the current experiment, higher recall meant more acceptance of wrong answers, which possibly broadened the overlapping network areas, creating more interference. It may be possible that having low working memory span could create a long-term lowering of good number sense by allowing the network to create higher familiarity values for wrong answers. Once the familiarity is increased, more network interference would be created. This would result in more errors being made as low span individuals, especially those with higher levels of math anxiety, tried to retrieve answers to simple addition stimuli.

APPENDIX

TABLES AND FIGURES

Table 1

The means and standard deviations of the findings from the background information sheet.

Demographic Variable	Math Anxiety Groups (SD in Parentheses) Low (n = 19)	Medium (n = 23)	High (n = 22)	
Low Span	**n =9**	**n = 10**	**n = 13**	
High Span	**n = 10**	**n = 13**	**n = 9**	
				Sig.
Gender (M/F)	11/8	8/15	7/15	ns
Age	23.42(11.38)	19.04(1.33)	20.68(3.05)	ns
Class Year	2.42(1.305)	1.7(1.06)	2.23(1.23)	ns
Number of H.S. math courses taken	4.22(1.215)	3.65(.573)	3.70(.70)	ns
H.S. math grade	3.39(.698)	3.09(.66)	2.91(.75)	ns
Number of college math courses taken	1.26(1.19)	1.00(1.08)	1.45(1.01)	ns
College math grade	3.25(.75)	3.11(.92)	2.38(.76)	$p < .05$
Rated math anxiety	4.21(2.72)	4.83(1.89)	6.68(1.78)	$p < .01$
Rated math enjoyment	6.05(2.43)	4.91(2.13)	3.64(2.21)	$p < .01$
sMARS score	17.95(6.03)	36.78(5.12)	57.23(8.93)	$p < .01$
Ethnic Group % of total				ns
African-American	10.5	8.7	27.3	
Hispanic/Latino	5.3	4.3	4.5	
Native American	5.3	N/A	N/A	
Asian/Pacific Islander	31.6	47.8	22.7	
Caucasuan	47.4	39.1	36.4	
Other	N/A	N/A	9.1	

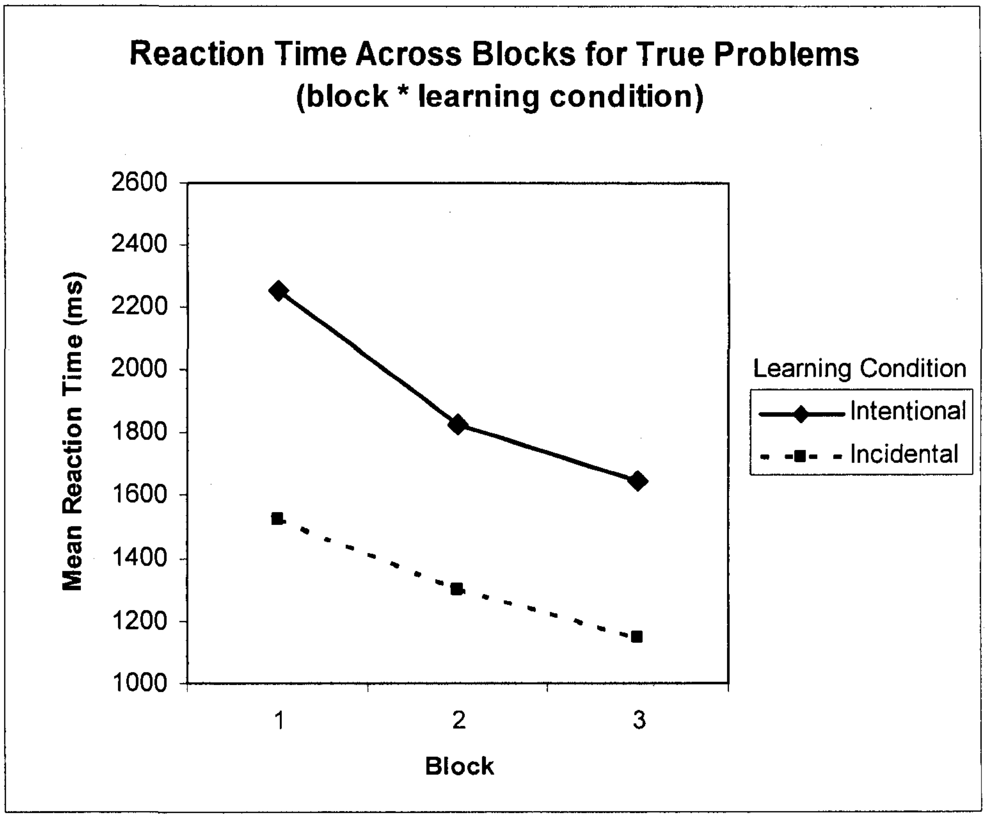

Reaction Time Across Blocks for True Problems
(block * learning condition)
Mean Reaction Time (ms)
2600
2400
2200
2000
1800
1600
1400
1200
1000
1
2
3
Block
Learning Condition
Intentional
Incidental

Figure 1

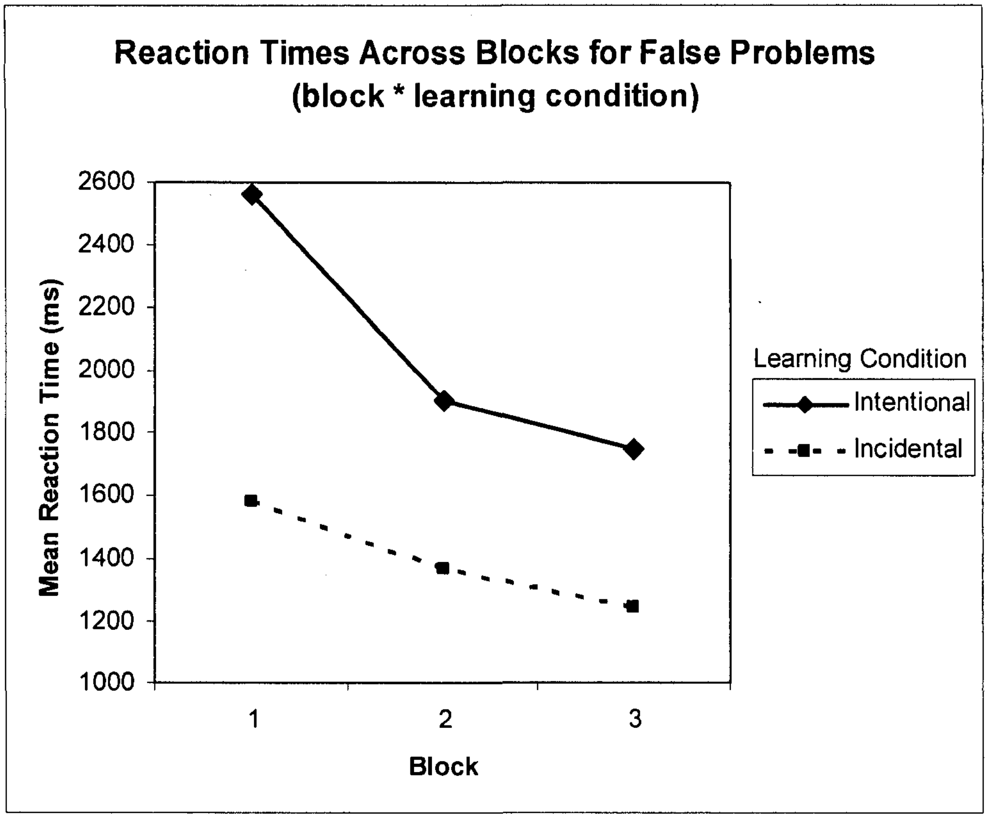

Reaction Times Across Blocks for False Problems
(block * learning condition)
Mean Reaction Time (ms)
2600
2400
2200
2000
1800
1600
1400
1200
1000
1
2
3
Block
Learning Condition
Intentional
Incidental

Figure 2

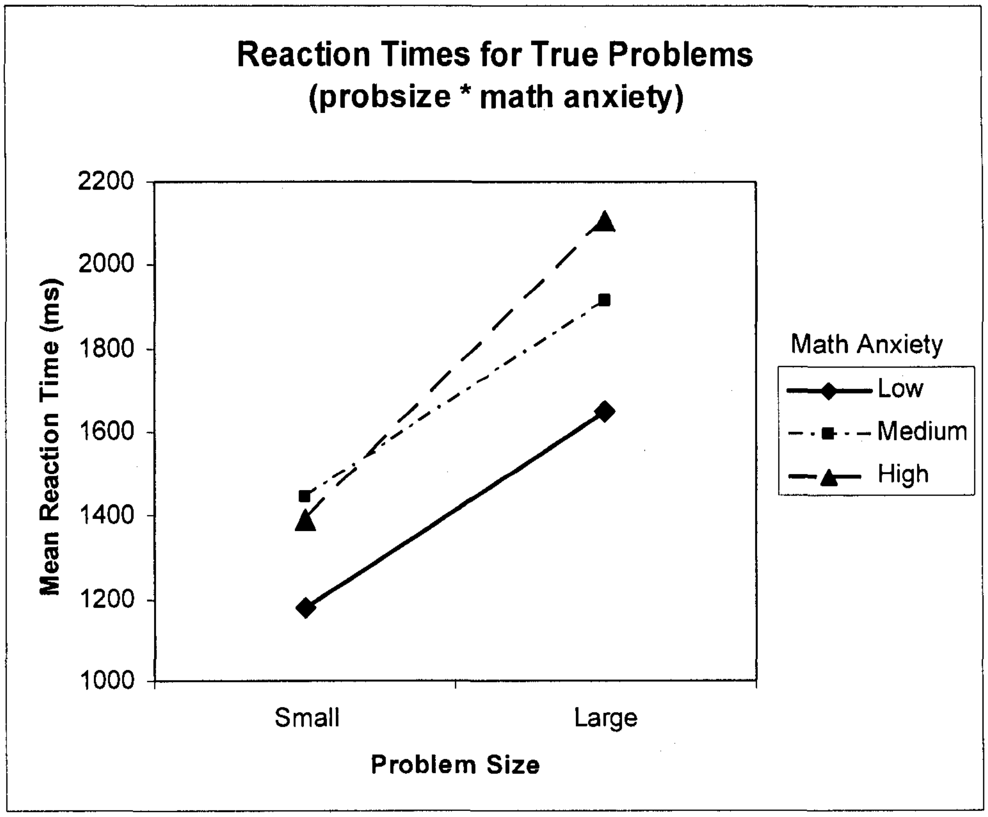
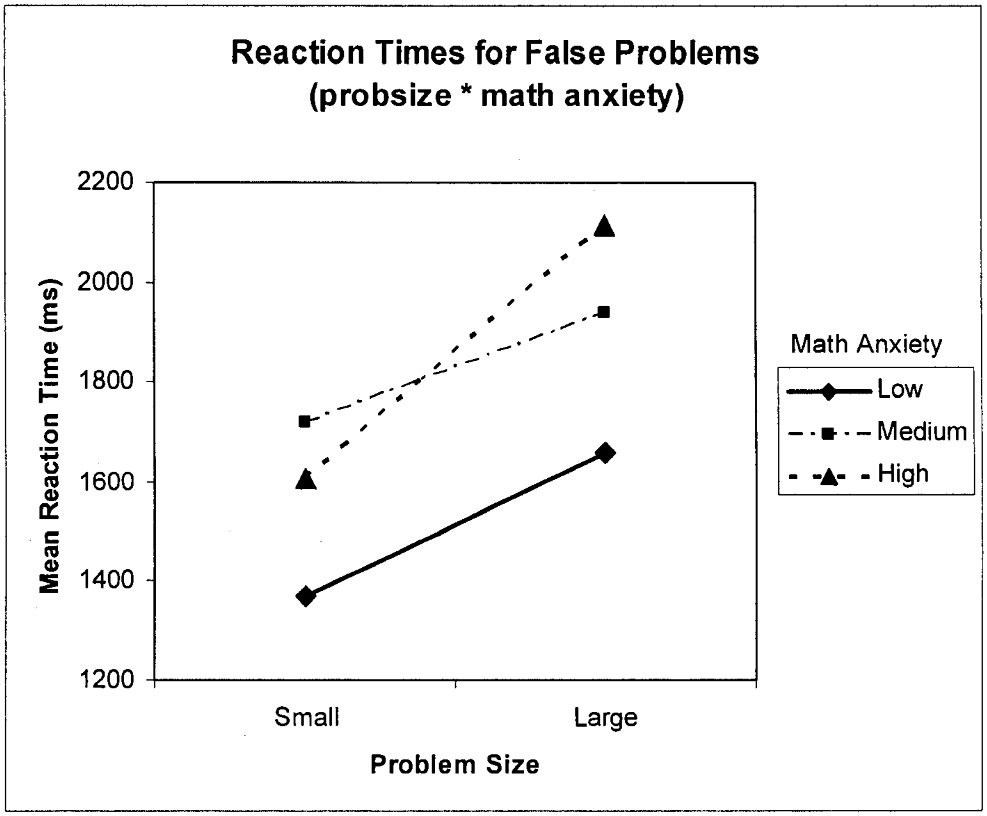

Reaction Times for True Problems
(probsize * math anxiety)
2200
2000
1800
1600
1400
1200
1000
Mean Reaction Time (ms)
Small
Large
Problem Size
Math Anxiety
Low
Medium
High

Figure 3



Reaction Times for False Problems
(probsize * math anxiety)
Mean Reaction Time (ms)
2200
2000
1800
1600
1400
1200
Small
Large
Problem Size
Math Anxiety
Low
Medium
High

Figure 4

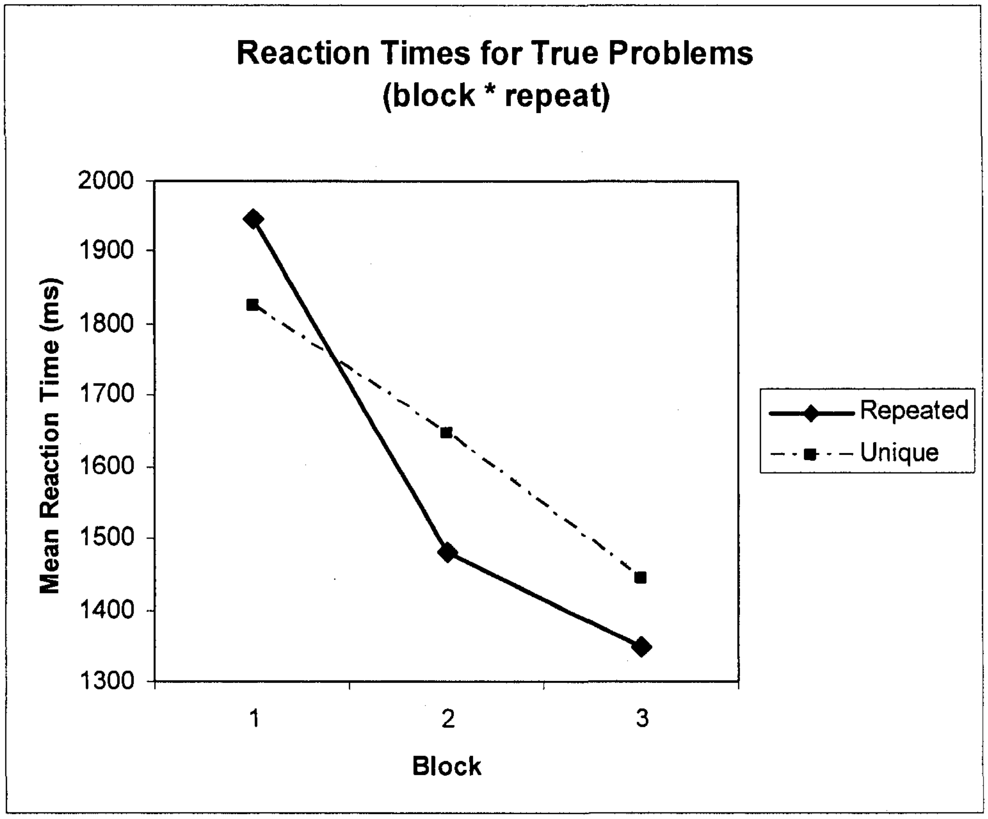
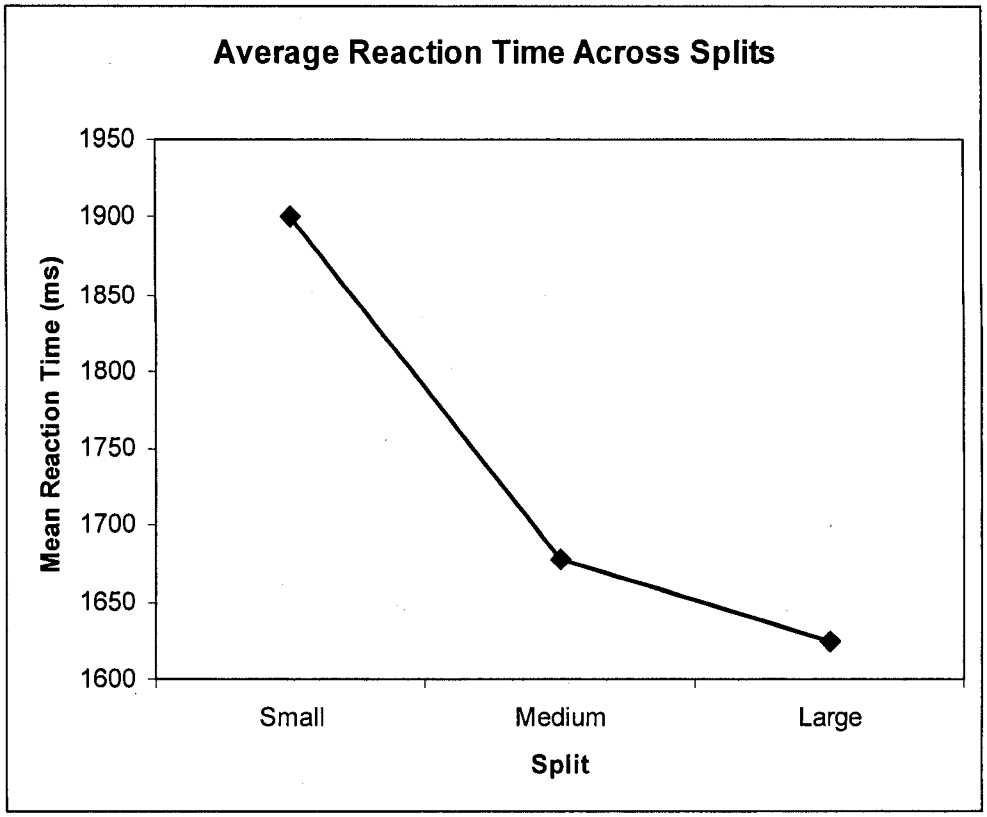

Reaction Times for True Problems
(block * repeat)
Mean Reaction Time (ms)
2000
1900
1800
1700
1600
1500
1400
1300
1
2
3
Block
Repeated
Unique

Figure 5



Average Reaction Time Across Splits
Mean Reaction Time (ms)
1950
1900
1850
1800
1750
1700
1650
1600
Small
Medium
Large
Split

Figure 6

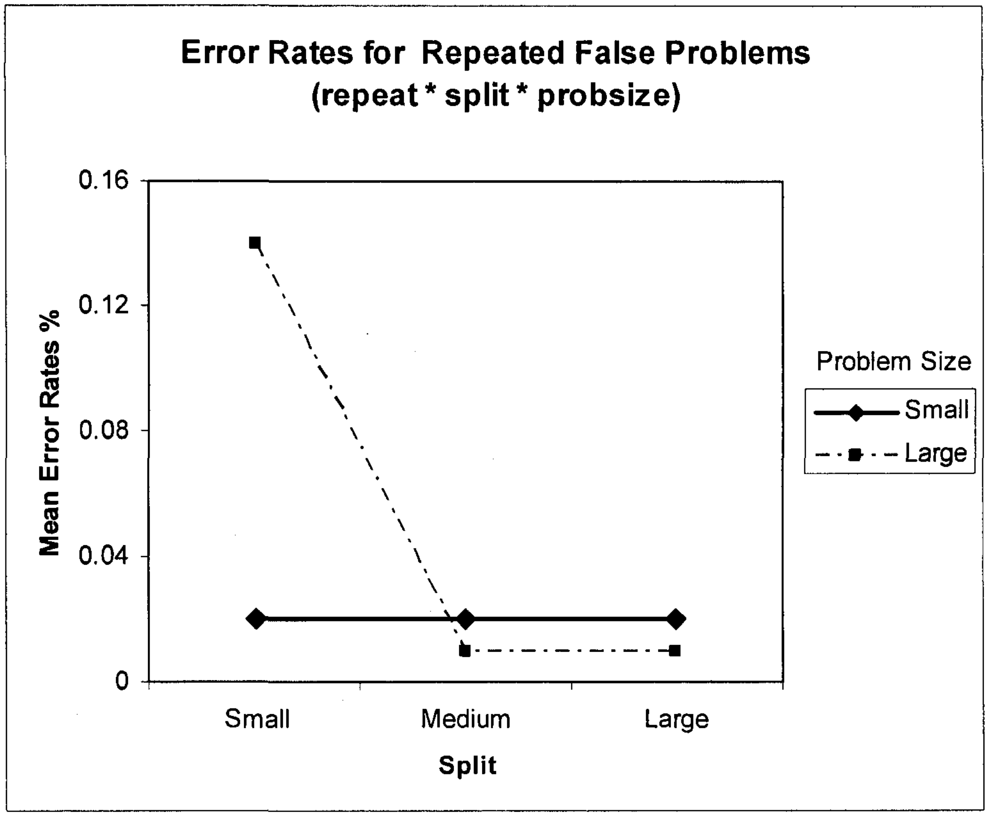

Error Rates for Repeated False Problems
(repeat * split * probsize)
0.16
0.12
0.08
0.04
0
Mean Error Rates %
Small
Medium
Large
Split
Problem Size
Small
Large

Figure 7

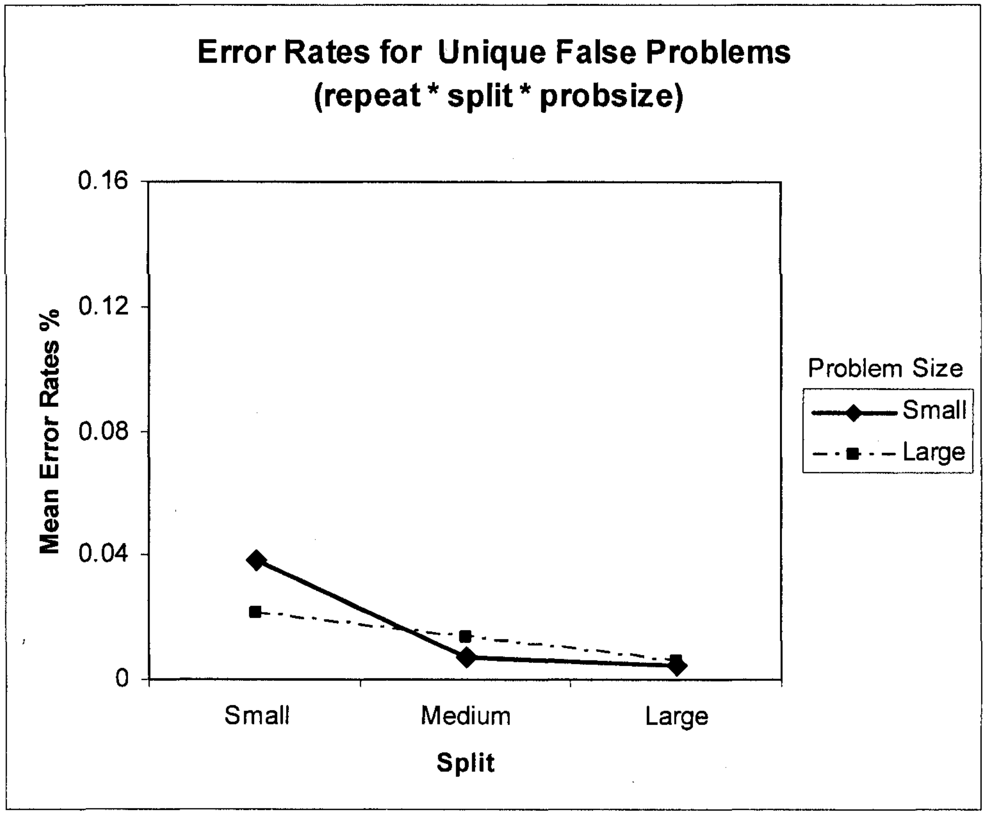

Error Rates for Unique False Problems
(repeat * split * probsize)
Mean Error Rates %
0.16
0.12
0.08
0.04
0
Small
Medium
Large
Split
Problem Size
Small
Large

Figure 8

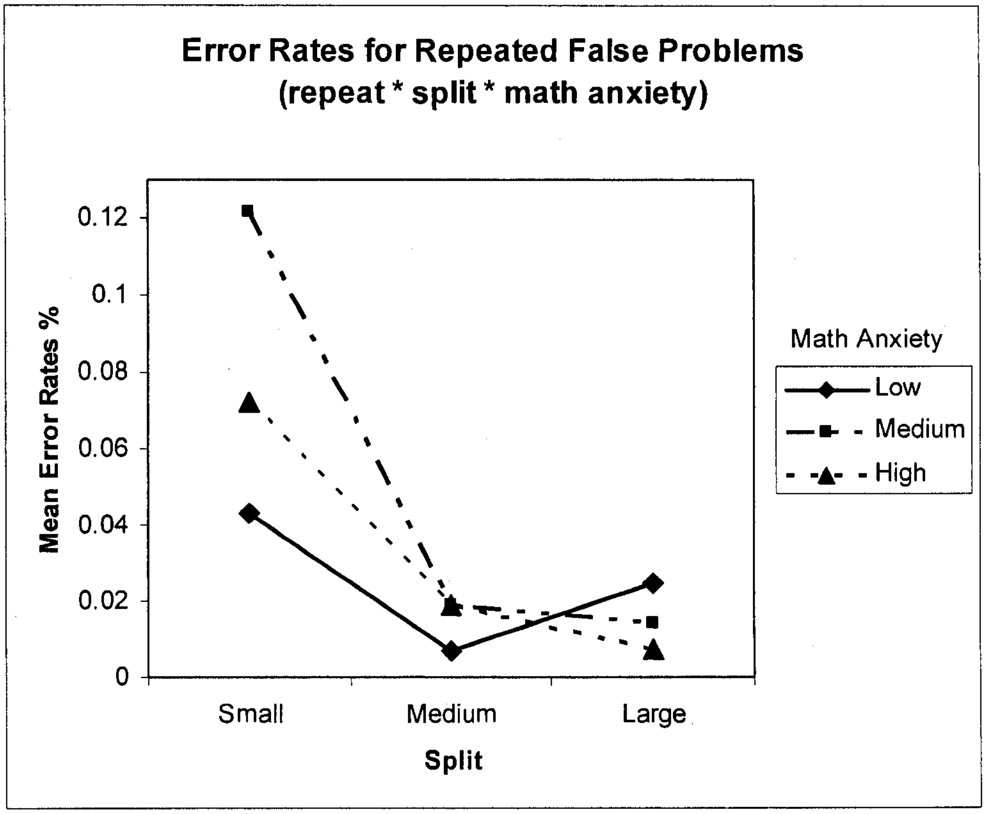

Error Rates for Repeated False Problems
(repeat * split * math anxiety)
Mean Error Rates %
0.12
0.1
0.08
0.06
0.04
0.02
0
Small
Medium
Large
Split
Math Anxiety
Low
Medium
High

Figure 9

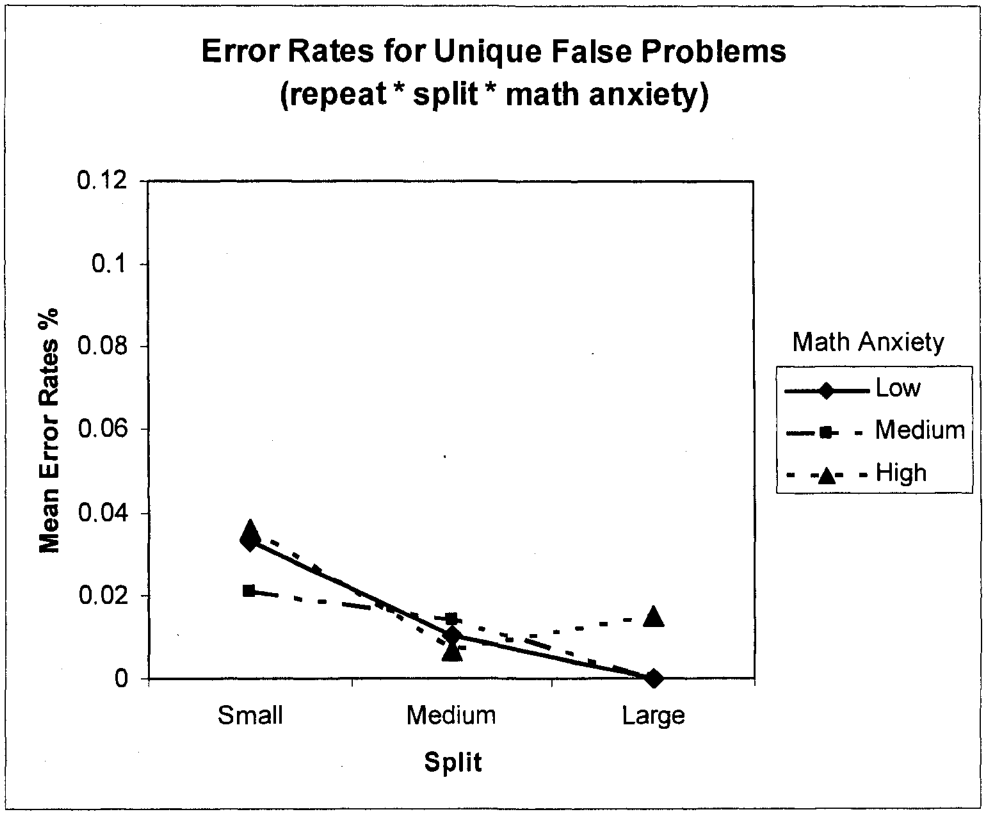

Error Rates for Unique False Problems
(repeat * split * math anxiety)
Mean Error Rates %
0.12
0.1
0.08
0.06
0.04
0.02
0
Small
Medium
Large
Split
Math Anxiety
Low
Medium
High

Figure 10

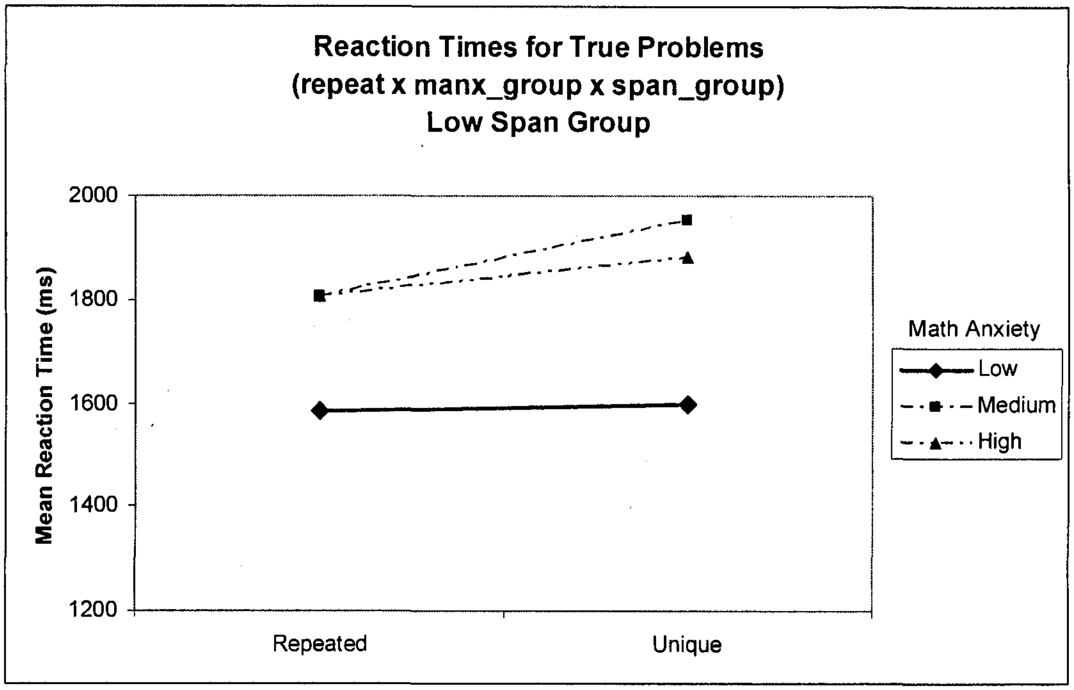

Reaction Times for True Problems
(repeat x manx_group x span_group)
Low Span Group
Mean Reaction Time (ms)
2000
1800
1600
1400
1200
Repeated
Unique
Math Anxiety
Low
Medium
High

Figure 11

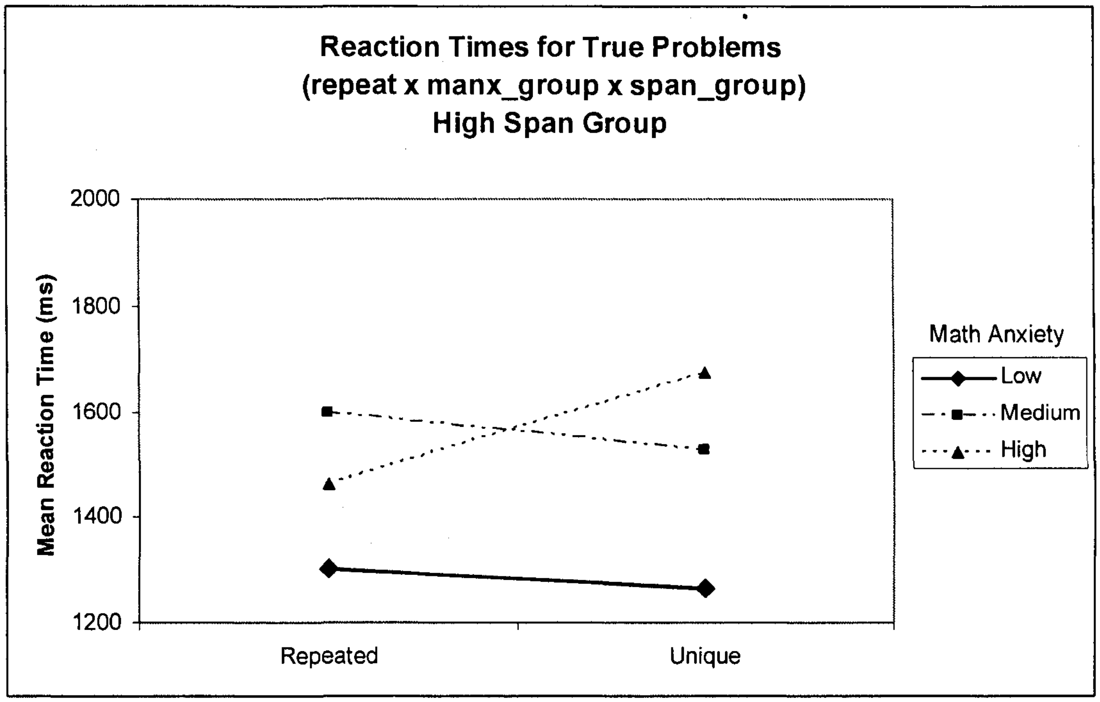

Reaction Times for True Problems
(repeat x manx_group x span_group)
High Span Group
Mean Reaction Time (ms)
2000
1800
1600
1400
1200
Repeated
Unique
Math Anxiety
Low
Medium
High

Figure 12

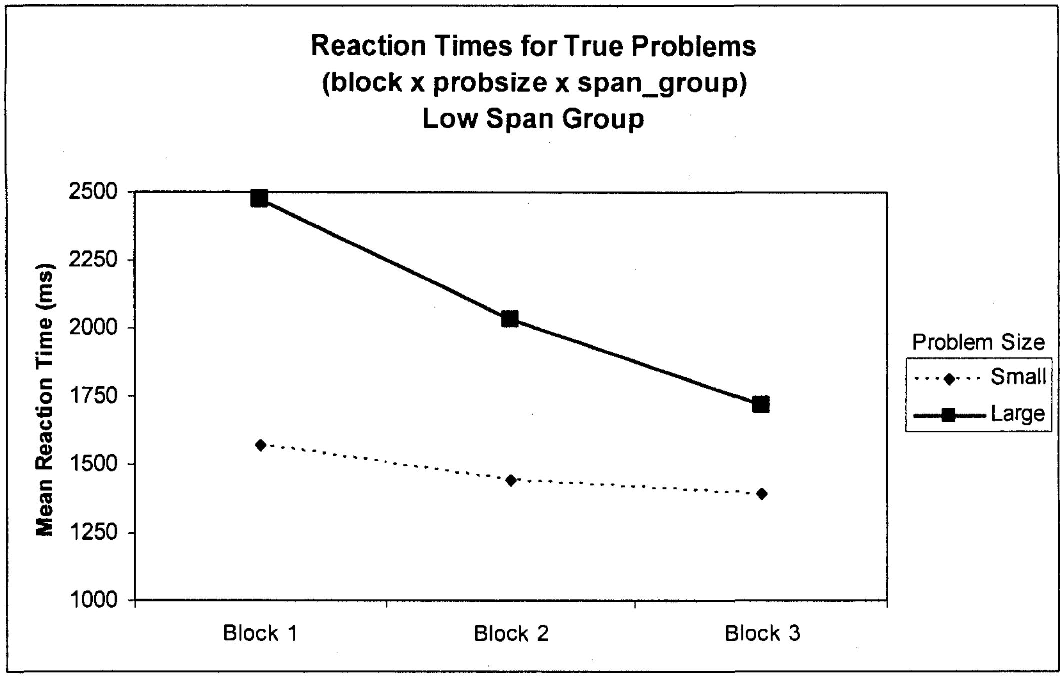

Reaction Times for True Problems
(block x probsize x span_group)
Low Span Group
Mean Reaction Time (ms)
2500
2250
2000
1750
1500
1250
1000
Block 1
Block 2
Block 3
Problem Size
Small
Large

Figure 13

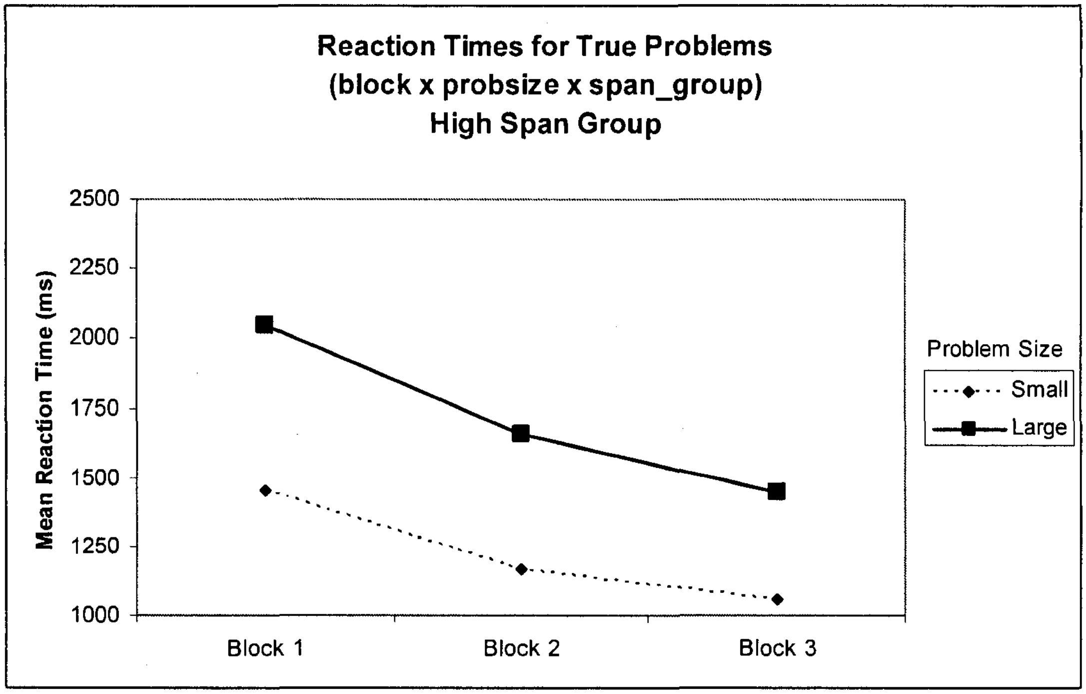

Reaction Times for True Problems
(block x probsize x span_group)
High Span Group
Mean Reaction Time (ms)
2500
2250
2000
1750
1500
1250
1000
Block 1
Block 2
Block 3
Problem Size
Small
Large

Figure 14

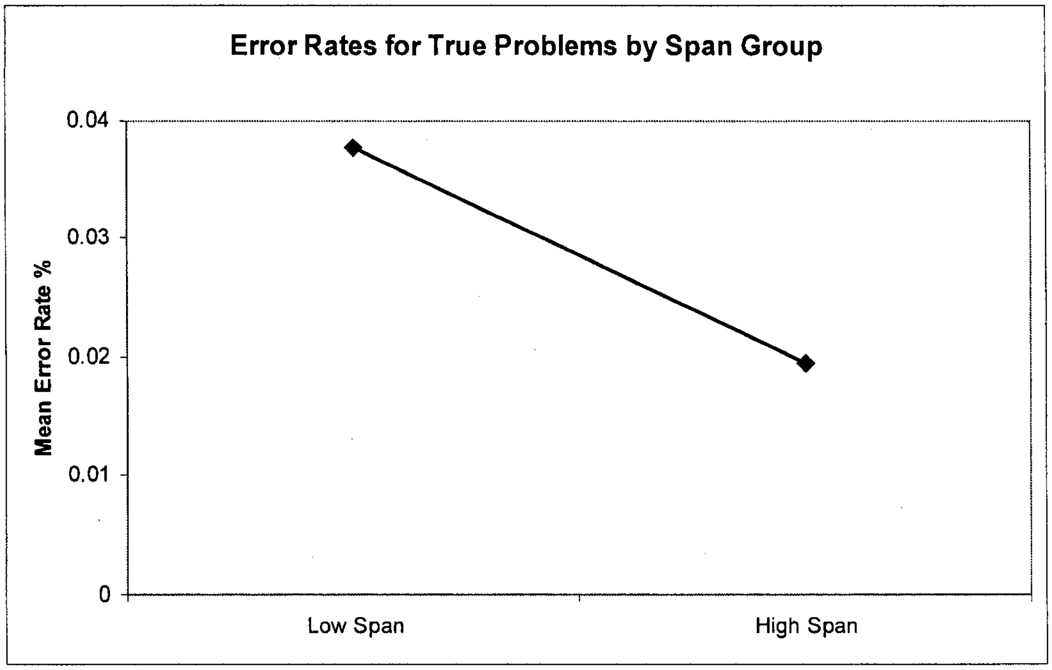

Error Rates for True Problems by Span Group
0.04
0.03
0.02
0.01
0
Mean Error Rate %
Low Span
High Span

Figure 15

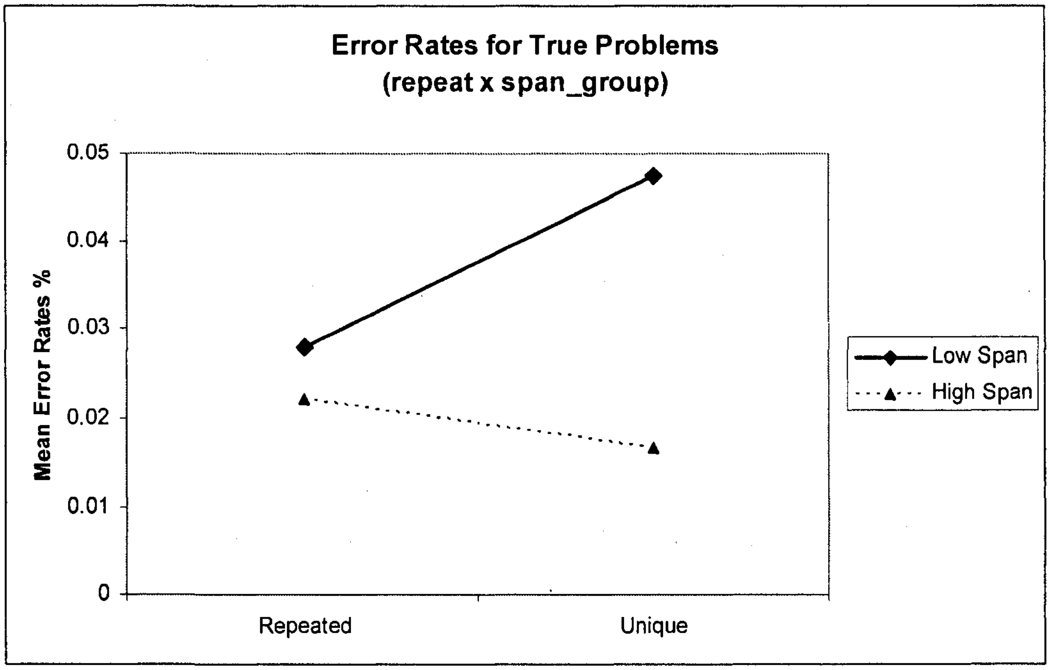

Error Rates for True Problems
(repeat x span_group)
Mean Error Rates %
0.05
0.04
0.03
0.02
0.01
0
Repeated
Unique
Low Span
High Span

Figure 16

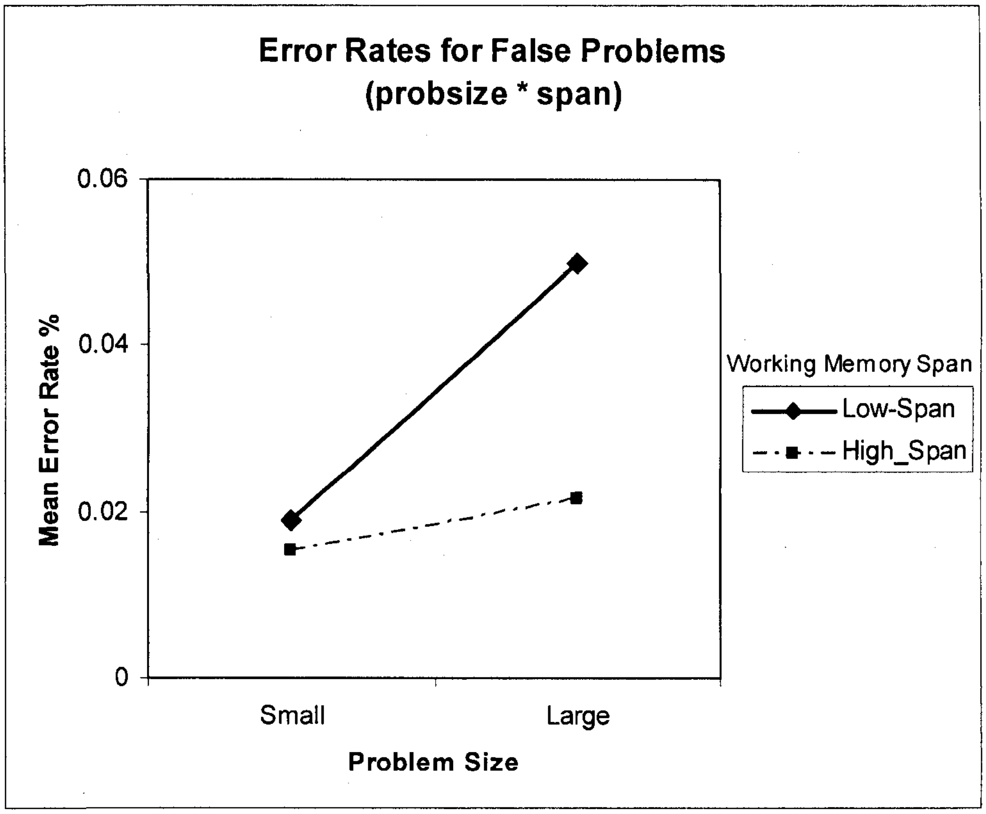

Error Rates for False Problems
(probsize * span)
0.06
0.04
0.02
0
Mean Error Rate %
Small
Large
Problem Size
Working Memory Span
Low-Span
High_Span

Figure 17

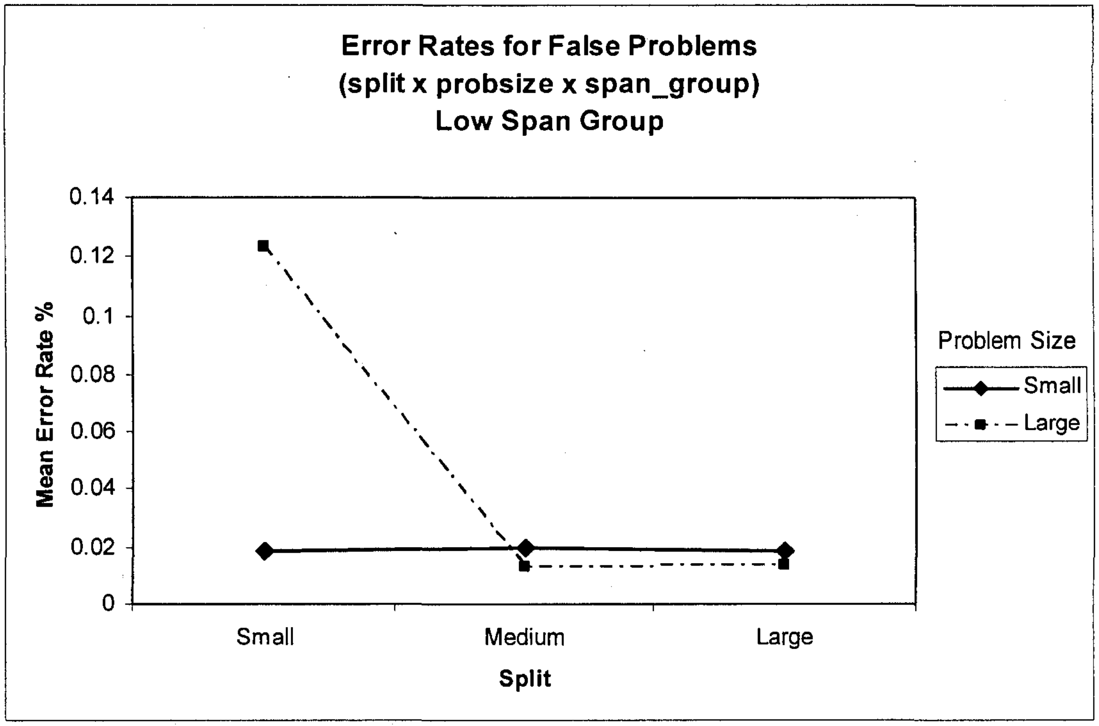
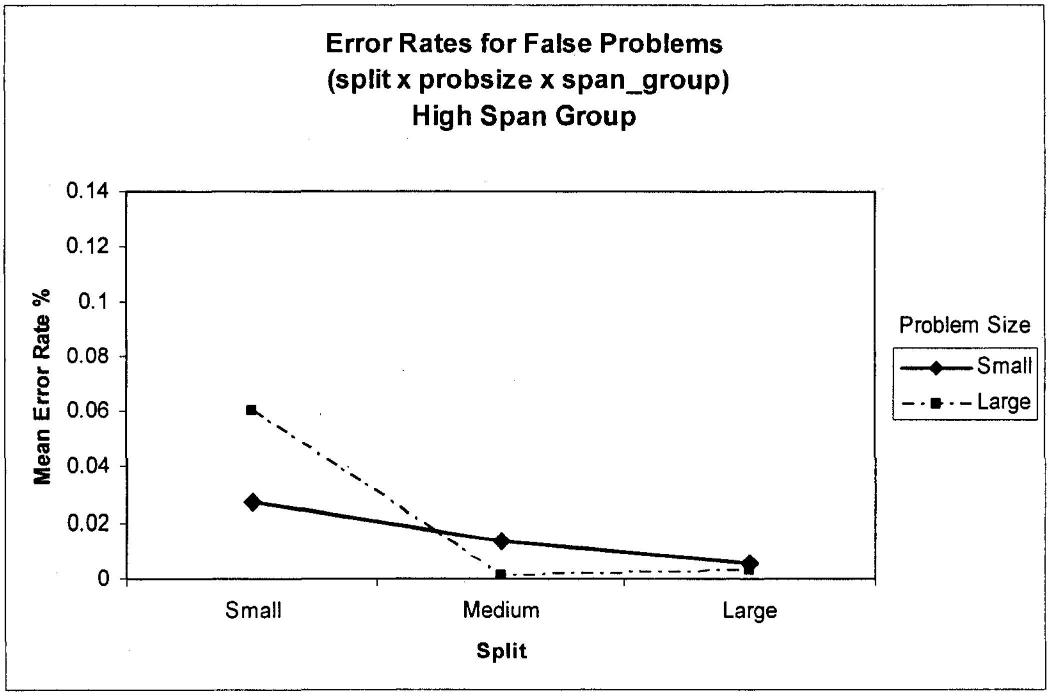

Error Rates for False Problems
(split x probsize x span_group)
Low Span Group
Mean Error Rate %
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Small
Medium
Large
Split
Problem Size
Small
Large

Figure 18



Error Rates for False Problems
(split x probsize x span_group)
High Span Group
Mean Error Rate %
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Small
Medium
Large
Split
Problem Size
Small
Large

Figure 19

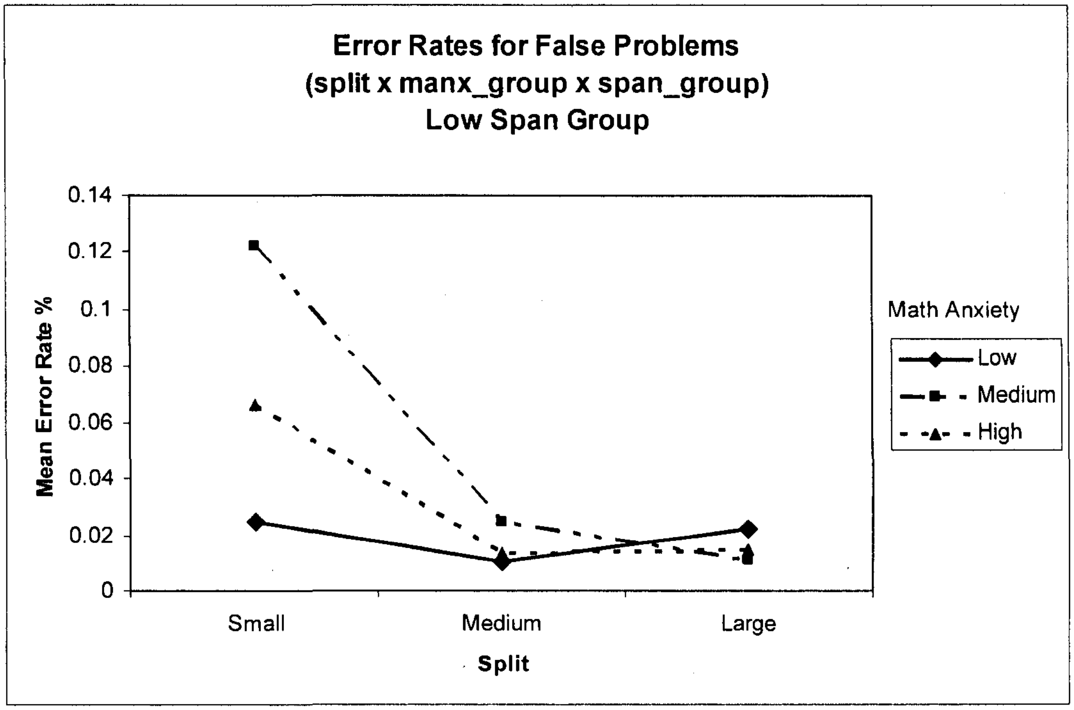

Error Rates for False Problems
(split x manx_group x span_group)
Low Span Group
Mean Error Rate %
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Small
Medium
Large
Split
Math Anxiety
Low
Medium
High

Figure 20

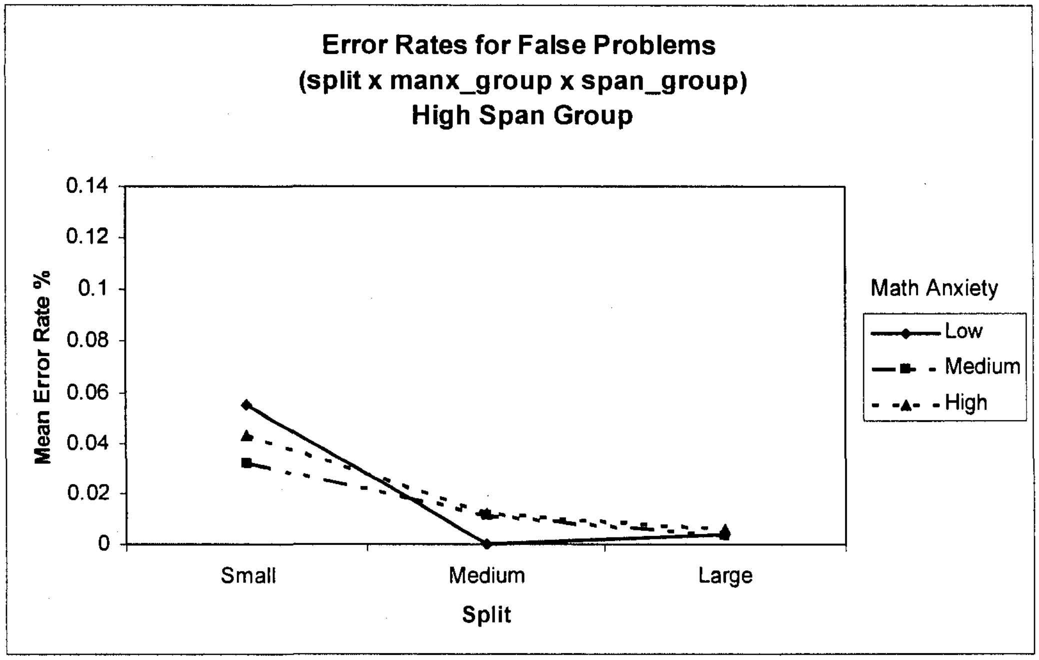

Error Rates for False Problems
(split x manx_group x span_group)
High Span Group
Mean Error Rate %
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Small
Medium
Large
Split
Math Anxiety
Low
Medium
High

Figure 21

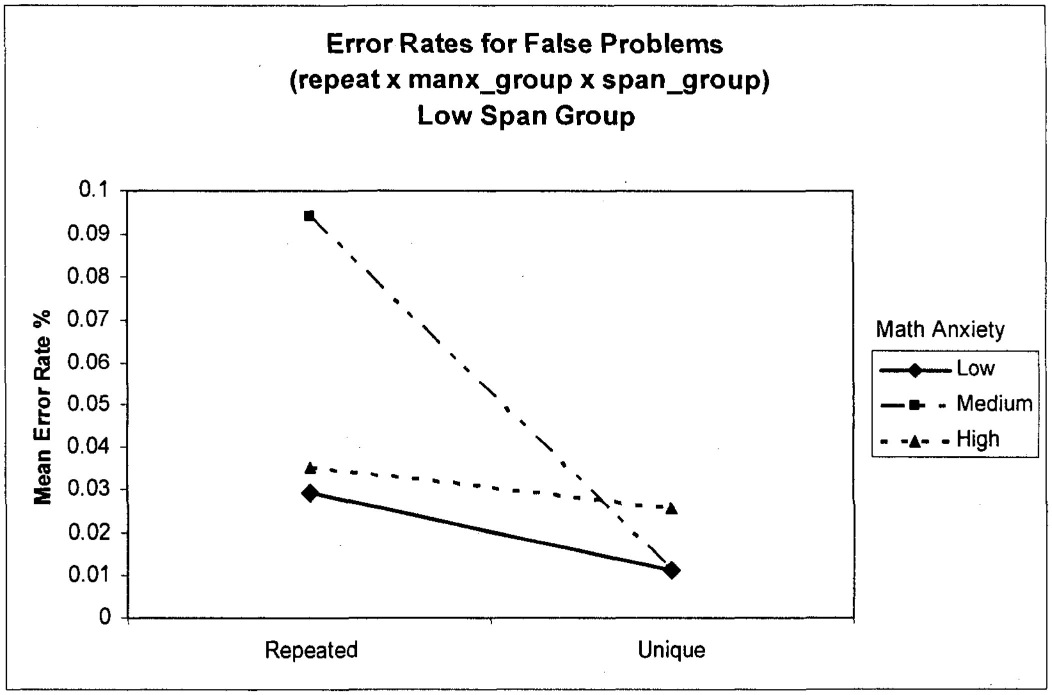

Error Rates for False Problems
(repeat x manx_group x span_group)
Low Span Group
Mean Error Rate %
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Repeated
Unique
Math Anxiety
Low
Medium
High

Figure 22

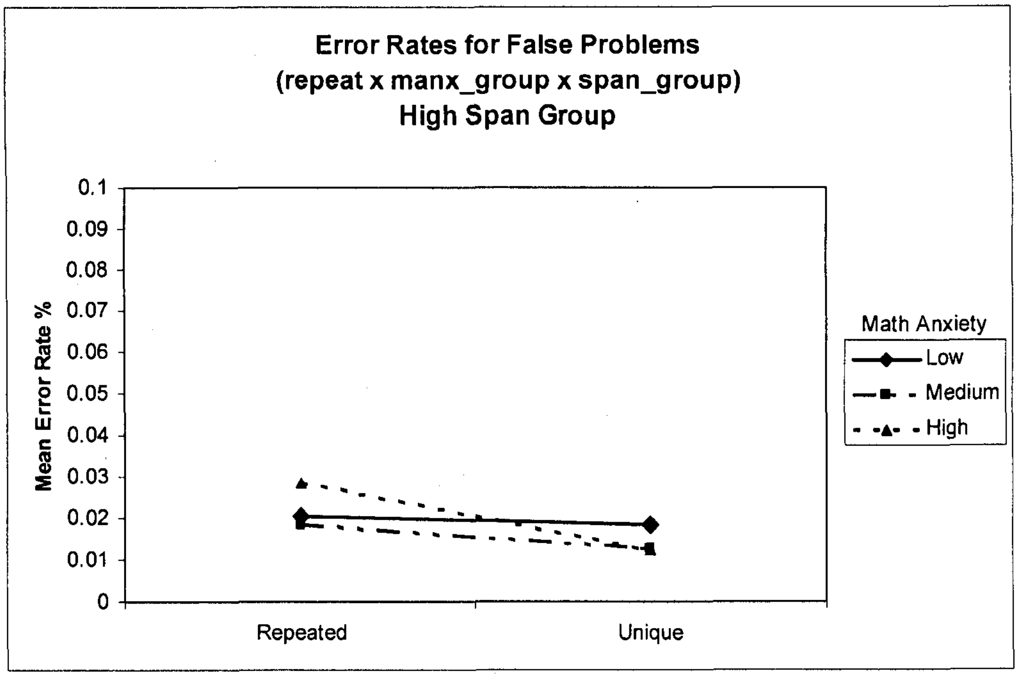

Error Rates for False Problems
(repeat x manx_group x span_group)
High Span Group
Mean Error Rate %
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Repeated
Unique
Math Anxiety
Low
Medium
High

Figure 23

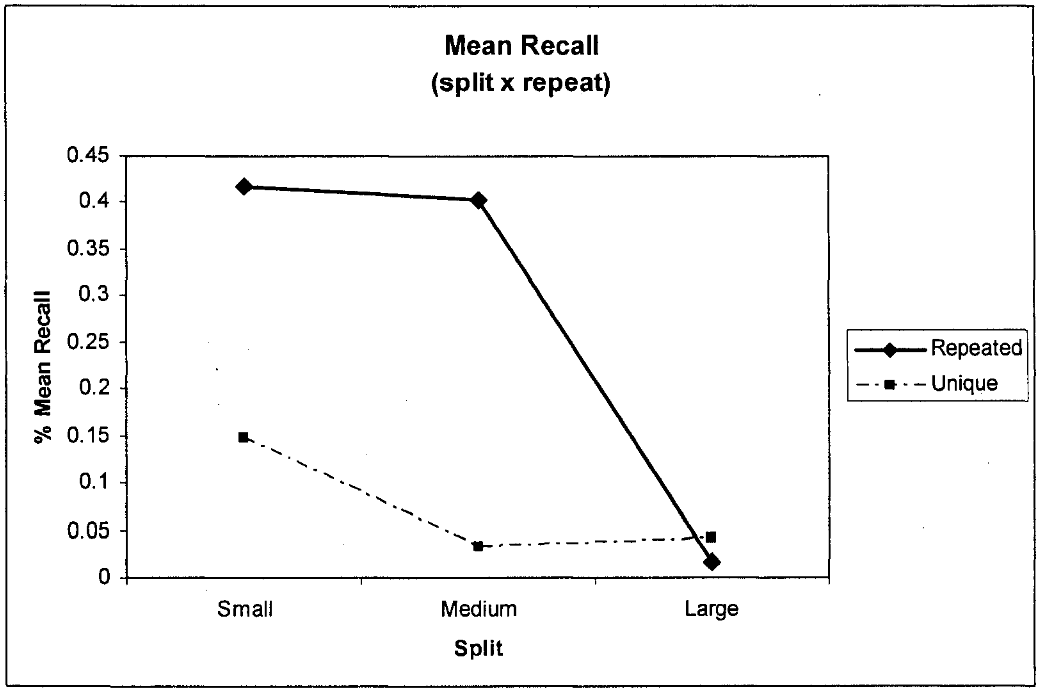

Mean Recall
(split x repeat)
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
% Mean Recall
Small
Medium
Large
Split
Repeated
Unique

Figure 24

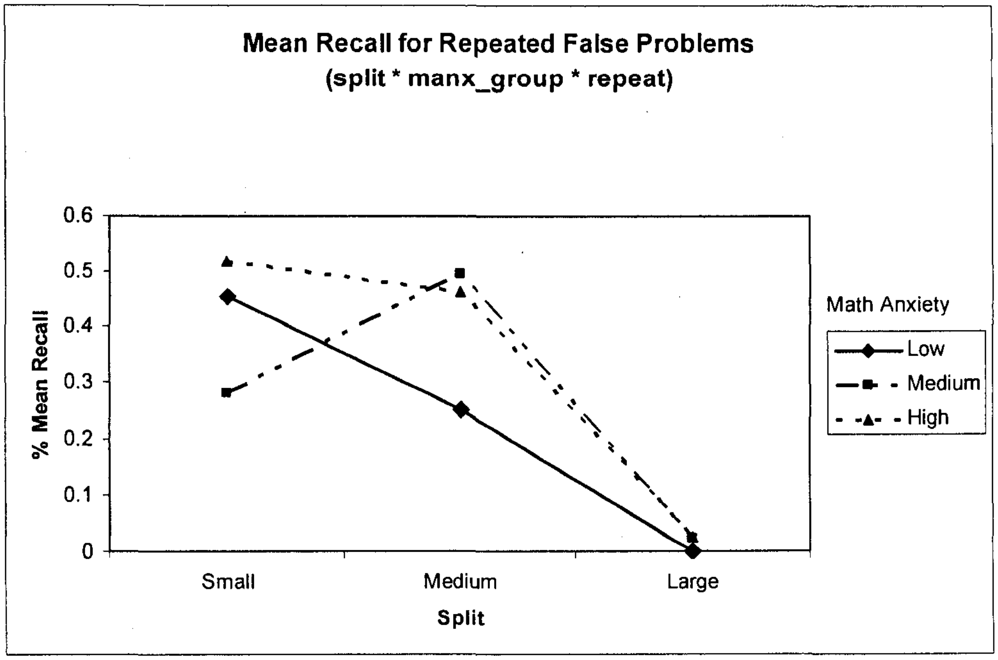

Mean Recall for Repeated False Problems
(split * manx_group * repeat)
0.6
0.5
0.4
0.3
0.2
0.1
0
% Mean Recall
Small
Medium
Large
Split
Math Anxiety
Low
Medium
High

Figure 25

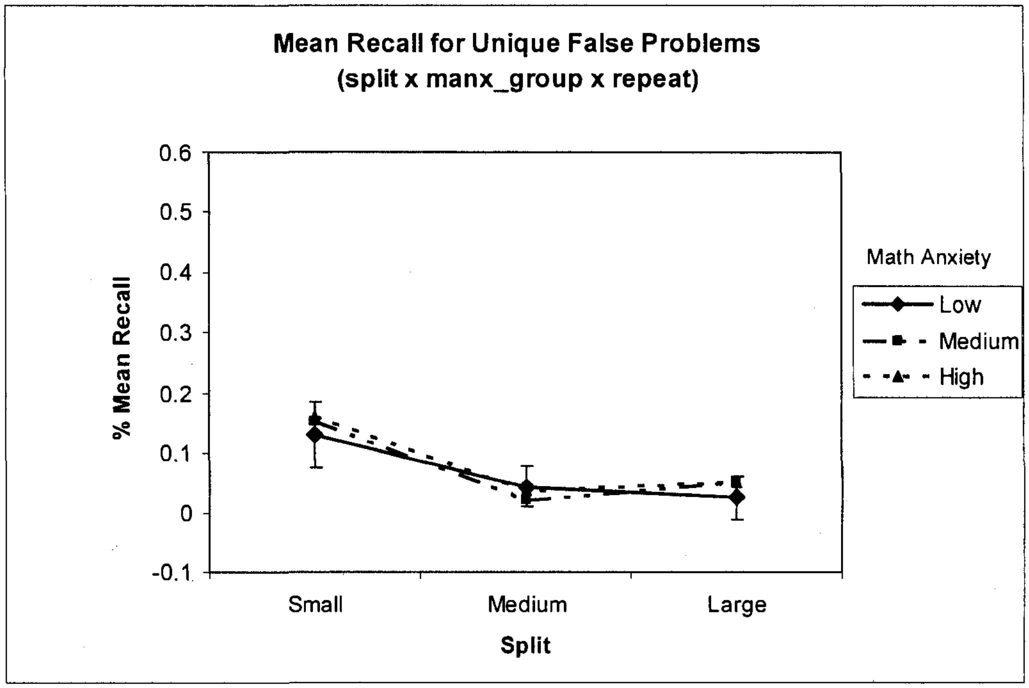

Mean Recall for Unique False Problems
(split x manx_group x repeat)
% Mean Recall
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
Small
Medium
Large
Split
Math Anxiety
Low
Medium
High

Figure 26

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