This study examined the effectiveness of a working memory intervention, Cogmed, in reducing mathematics anxiety in elementary students from an urban district. Mathematics anxiety, working memory, and mathematics performance were measured using the Mathematics Anxiety Rating Scale - Elementary (Suinn, Taylor, & Edwards, 1988), three subtests from the Wechsler Intelligence Scale for Children-Fourth Edition (Wechsler, 2003), and the Calculation subtest from the Woodcock-Johnson Psychoeducational Battery – Third Edition (Woodcock, McGrew & Mather, 2001) respectively. Results showed a significant correlation between working memory and mathematics performance. Significant increases in working memory and mathematics performance were found after the completion of the working memory intervention. No significant reductions in mathematics anxiety were found. These results indicate that stronger working memory is associated with higher mathematics performance, which was further supported by the significant gains achieved in participants’ working memory capacities and mathematics performance after completion of the working memory intervention.
MATHEMATICS ANXIETY, WORKING MEMORY, AND MATHEMATICS PERFORMANCE: EFFECTIVENESS OF A WORKING MEMORY INTERVENTION ON REDUCING MATHEMATICS ANXIETY

A Thesis

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## Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Review of the Literature</td>
<td>4</td>
</tr>
<tr>
<td>Research Design</td>
<td>16</td>
</tr>
<tr>
<td>Results</td>
<td>19</td>
</tr>
<tr>
<td>Discussion</td>
<td>24</td>
</tr>
<tr>
<td>References</td>
<td>27</td>
</tr>
<tr>
<td>Appendices</td>
<td>31</td>
</tr>
</tbody>
</table>
List of Tables

Table 1 General Frequency Statistics 20
Table 2 Pearson Correlation Coefficients 21
Table 3 Paired Samples t-tests for Pretest-Posttest Measures 22
Table 4 ANOVA Summary for Grades 23
Introduction

Mathematics anxiety is a feeling of tension and anxiety that interferes with the manipulation of numbers and solving of mathematical problems in many settings (Richardson & Suinn, 1972). Mathematics anxiety varies in severity (Ashcraft & Moore, 2009) and can be found in all ages. One study found that 16% of the participants experienced mathematics anxiety as early as grades 3 or 4 (Jackson & Leffingwell, 1999).

Several different studies have found a negative correlation between mathematics anxiety and mathematics performance (Ashcraft & Moore, 2009; Ma, 1999; Zakaria & Nordin, 2008; Mazzone et al., 2007), suggesting that as mathematics anxiety increases, performance decreases. A meta-analysis found a significant negative correlation of ($r = -.27$) between mathematics anxiety and mathematics performance. This may imply that mathematics performance scores for students with mathematics anxiety may underestimate true ability due to the deleterious impact that anxiety presents.

Working memory is a cognitive process that allows a person to multitask, or simultaneously think about and hold information at the same time as completing other tasks, and is responsible for temporarily storing and manipulating information (Alloway, 2006; Klingberg, Forssberg, & Westerberg, 2002). Ashcraft and Kirk (2001) examined and found a negative relationship between mathematics anxiety and working memory among undergraduate students, implying that the presence of mathematics anxiety may compromise working memory.

Working memory has been found to be important in many areas of academics, and extensive research has connected working memory to performance, specifically in mathematics. Students with poor working memory capacity will often struggle with academics, therefore, leading to poor academic progress (Alloway, 2006). Studies on working memory have shown a link with performance among primary aged students (Gathercole & Pickering, 2000). Gathercole et al. (2004) conducted a study that looked at the relationship between working memory skills and performance on national curriculum assessments among children. Results found close associations between children’s scores on working memory measures and their national curriculum assessments. The children that performed poorly on the assessment also had poor working memory, which in turn is thought to limit an individual’s ability to meet the demands in the classroom.
In 2001, a computerized training program was designed to increase working memory performance (Cogmed, 2006). This program, developed by Cogmed, requires participants to complete a series of tasks that require the storage and manipulation of verbal and visuospatial information on a daily basis for five weeks. Use of this program has helped improve working memory in individuals who have suffered from ADHD (Klingberg, et al., 2002; Klingberg, et al., 2005; Holmes, Gathercole, Place, Dunning, Hilton, & Elliott, 2009b). Moreover, a study was conducted to examine if attention (a component of working memory), could be improved in children with ADHD between ages 7 and 15. Results showed that the children receiving the Cogmed intervention improved. The computerized working memory training gradually increased the amount of information that the students could keep in working memory. Klingberg et al. (2002) repeated this study with 4 male adults without ADHD and found similar results.

Significant relationships have been made between mathematics anxiety, working memory, and mathematics performance. As mathematics anxiety increases, an individual’s working memory is compromised (Ashcraft & Kirk, 2001). If an individual has a compromised working memory, mathematics performance will in turn be affected and decrease (Gathercole & Pickering, 2000; Gathercole et al., 2004; Seyler et al., 2003). In order to increase mathematics performance and decrease mathematics anxiety, working memory deficits must be addressed. Thus far studies have been conducted and investigated the positive impact of Cogmed as an evidenced-based working memory intervention. Based on the relationship between mathematics anxiety, working memory, and mathematics performance, it is thought that Cogmed may prove to be an effective mathematics anxiety intervention. By increasing working memory capacity, an individual will not be as affected by the inner worries and doubts that once controlled their working memory processes.

The present study seeks to complement and extend the research completed by Holmes et al. (2009a) by reexamining the effects of Cogmed’s working memory training on mathematics anxiety levels in elementary students. This study hopes to examine whether Cogmed’s computerized, evidence-based training program can improve individual student’s working memory performance and mathematical achievement, and in turn, consequently reduce levels of mathematics anxiety in a small group of urban summer school students. Findings from this study
will help to evaluate the usefulness of computerized, cognitive training as a working memory, mathematics achievement, and/or mathematical anxiety intervention among an urban sample of elementary students. Because correlations have been found between mathematics anxiety, working memory, and mathematics performance, it was hypothesized that 1) mathematics anxiety would negatively correlate with working memory and mathematics performance and that working memory would positively correlate with mathematics performance. 2) that participation with Cogmed would result in reduced mathematics anxiety and increase working memory and mathematics performance among elementary students, and 3) that students in the older grades would have greater gains in working memory and mathematics performance and greater reductions in mathematics anxiety than students in the lower grades.
Mathematics Anxiety

Mathematics anxiety is a concern that has been frequently studied in recent years, especially because of increased emphasis schools are placing on testing standards. Since testing has become so important for many schools, students sometimes feel this pressure and experience anxiety before, during, and related to testing. Students often experience anxiety during mathematics across many contexts, including high risk testing and low risk classroom situations. Mathematics anxiety is a serious problem for students because it impacts their success and sense of efficacy in school. Richardson and Suinn (1972) define mathematics anxiety as a feeling of tension and anxiety that interferes with the manipulation of numbers and solving of mathematical problems in many settings. People can experience mathematics anxiety in school, during standardized tests, when balancing a check book, or while figuring the tip at a restaurant (Ashcraft & Moore, 2009). A moderate amount of anxiety can facilitate thinking, but beyond a certain point these feelings of tension and anxiety can be severe and create an overwhelming emotional and physiological disruption (Kargar, Tarmizi, & Bayat, 2010). Mathematics anxiety affects a considerable portion of the population (Ashcraft & Moore, 2009), individuals both young and old. The exact prevalence of individuals that suffer from mathematics anxiety is difficult to determine because it is not an easy concept to measure and often goes undetected. Campbell (2005) estimates that about 20% of individuals may qualify as having high mathematics anxiety. This does not necessarily mean that 20% of the population suffers from mathematics anxiety, but it does suggest that many people are affected by mathematics anxiety.

Although mathematics anxiety impacts individuals of all ages, it begins at an early age (Perry, 2004). It has been found to be relatively common among children and interferes with their functioning in maladaptive ways (Mazzone, Ducci, Scoto, Passaniti, D’Arrigo, & Vitiello, 2007). Children are introduced to mathematics early in life, and formal mathematics education begins as early as pre-school (Begley, 2007). Some researchers suggest that mathematics anxiety emerges as early as grade 3 or 4 (Jackson & Leffingwell, 1999; Ashcraft & Moore, 2009; Ma, 1999), and addressing this issue as early as possible will have the greatest benefit for affected students.

Jackson and Leffingwell (1999) conducted a study to determine the grade levels (kindergarten – college) in which mathematics anxiety first occurred among 154 teacher
education students in a senior-level-elementary-mathematics course that were seeking certification in elementary education. Each participant was asked, “Describe your worst or most challenging mathematics classroom experience from kindergarten through college.” The respondents were also asked to describe factors that would have made their experiences more positive. The results found that only 7% of the participants had positive experiences in their mathematics classes, ranging from kindergarten through college. Of the participants, 16% experienced mathematics anxiety starting in grades 3 or 4, 26% in grades 9, 10, and 11, and 27% during freshman year in college. Although grades 3 and 4 did not have the highest rates of initial mathematics anxiety occurrence, many young students are affected by mathematics anxiety and this should be examined further. It is also possible that anxious feelings about mathematics started much earlier than the reported “most challenging” mathematics experience in this study.

Mathematics Anxiety and Performance

With the increasing number of high-stakes tests that students are required to take in today’s education system, performance matters. How well students perform on these tests determines whether a student passes grade level, graduates, or is admitted into college. Several different types of studies have found a negative correlation between mathematics anxiety and mathematics performance (Ashcraft & Moore, 2009; Ma, 1999; Zakaria & Nordin, 2008; Mazzone et al., 2007). This relationship suggests that as mathematics anxiety increases, mathematics performance decreases. Clearly, this is not the relationship that teachers, administrators, parents, or students want to see because low performance will affect the student’s future. These assessments that are meant to benefit students by keeping them accountable may have a detrimental effect on mathematics performance because of the increased pressure and anxiety that students experience.

Ashcraft and Moore (2009) provided a review of the history of mathematics anxiety, its relationship to personal and educational consequences, and its impact on measures of performance. They reported that mathematics anxiety leads to a dramatic decrease in performance when mathematics is under timed, high-stakes conditions. When placed in high-stakes testing environments, anxious students must deal with their anxieties on top of the demands of the test and the difficulty of the mathematics material. This means that mathematics achievement and proficiency scores for mathematics anxious individuals are underestimates of
true ability. If this is true, then the alleviation of mathematics anxiety in these students may lead to better performance on the achievement tests.

Zakaria and Nordin (2008) investigated the effects of mathematics anxiety on 88 college students (73 females, 15 males) as related to motivation and achievement. Assessments used in this study included the Mathematics Anxiety Scale (measured mathematics anxiety), the Effectance Motivation Scale (measured motivation), and the Mathematics Achievement Test (measured achievement). The participants were divided into three groups based on anxiety scores. The scores that fell between 33% and 67% comprised the moderate group. The low and high anxiety groups consisted of students who were in the lower 33% and in the upper 33% of the distribution. The results found that the mean achievement and motivation scores for the three anxiety groups were significantly different, $F(2,85) = 3.75, p < .05$. Significant negative correlations were found between mathematics anxiety and achievement ($-.32$) and mathematics anxiety and motivation ($-.72$). This indicates that higher mathematics anxiety is correlated with lower achievement and motivation levels. The study was conducted with college aged individuals, and one would suspect that similar results would be found among elementary students. Based on these results, it is possible that if students did not feel as much anxiety towards mathematics, they would not only achieve higher on performance measures, but would also experience increased interest, satisfaction, and confidence in mathematics.

Mazzone et al. (2007) conducted a study that examined the levels of self-reported anxiety symptoms in 478 children and adolescents (222 females, 256 males) across different ages (elementary: 8-10 years, middle: 11-13 years, high: 14-16 years) and the relationship between self-reported anxiety symptoms and school performance. The measures used included the Multidimensional Anxiety Scale for Children (measured anxiety symptoms) and overall grades (measured school performance). Results found that anxiety scores were not significantly different among the three age groups. Out of the participants, 35 students were considered to have anxiety (elementary: 3/131, middle: 21/267, high: 11/80). Of these students, there was a significant negative relationship between anxiety scores and academic grades (elementary: 2/3, middle: 13/21, high: 10/11), meaning higher anxiety was related to lower performance. In the whole sample, children with high anxiety scores were more likely to have insufficient grades (37%) than children who did not have high anxiety scores (28%). From this study it can be concluded that anxiety symptoms increase with age, and that high levels of anxiety were
negatively associated with school performance. Although a significant relationship was found with overall grades in this case, it would be plausible to expect this relationship to exist specifically in mathematics based on other relevant research.

Ma (1999) conducted a meta-analysis of 26 studies (totaling 18,279 students, grades 4-12) addressing the relationship between mathematics anxiety and achievement in mathematics among elementary and secondary students. There were 6 instruments used to measure anxiety among these studies, the Mathematics Anxiety Rating Scale being the most frequent, and 9 instruments used to measure achievement in mathematics. Results found the common population correlation between mathematics anxiety and mathematics achievement to be -.27. This negative relationship between mathematics anxiety and mathematics achievement was significant from grade 4 on, which further supports the notion that mathematics anxiety does not only exist in the primary grades, but has an adverse effect on mathematics achievement throughout the grades. This study serves to strengthen the assertion that a negative relationship exists between mathematics anxiety and mathematics achievement.

**Mathematics Anxiety and Working Memory**

Working memory is a cognitive process which allows a person to multitask, or simultaneously think about and hold information at the same time as completing other tasks. It is a system responsible for temporarily storing and manipulating information (Alloway, 2006). Eysenck and Calvo’s (1992) model of general anxiety effects hypothesized that general anxiety disrupts ongoing working memory processes because anxious individuals devote attention to their intrusive thoughts and worries, rather than the task at hand. These are some of the same effects observed in individuals with mathematics anxiety. Paying attention to these intrusive tasks acts like a secondary task, thus diverting attention from the mathematics task (Ashcraft, 2002). Two studies conducted and reported by Ashcraft and Kirk (2001) examined and found a negative relationship between mathematics anxiety and working memory, implying that the presence of mathematics anxiety may compromise working memory.

The first study explored whether mathematics anxiety disrupts working memory among three groups of 15 undergraduate students of varying levels of mathematics-anxiety (Ashcraft & Kirk, 2001). The assessments used in this study included the Short Mathematics Anxiety Rating Scale (measured levels of apprehension and anxiety about mathematics) and a demographic sheet. The experiment was carried out on a computer using the Micro Experimental Laboratory.
that presented all instructions on the screen and recorded response times. There were three events for each trial: a) presented a set of letters to be held in working memory (encouraged to read aloud), b) presented the addition problem to be solved (response time began when the problem appeared on the screen), and c) prompted for recall of the letters (orally). The results of this study confirmed that high-mathematics-anxiety individuals have difficulties with addition problems involving a carrying operation. When carrying was performed simultaneously with a task that placed heavy loads on working memory, performance decreased sharply for the high-mathematics-anxiety group. This suggests that individuals with high mathematics anxiety will experience a decrease in mathematics performance due to lower working memory capacity.

In order to expand upon this relationship between compromised working memory and mathematics anxiety, the second study by Ashcraft and Kirk (2001) sought to explore the limits of this effect. In this study, performance on an intensive working memory task that did not require an overt use of learned mathematics was examined among three groups of 15 undergraduate students displaying varying levels of mathematics-anxiety. The assessments used included the short Mathematics Anxiety Rating Scale (measured levels of apprehension and anxiety about mathematics) and a demographic sheet. The experiment was also carried out on a computer using the Micro Experimental Laboratory software package. Working memory capacity and processing were assessed by giving participants two types of tasks: a) series of letter transformation trials: participants were presented with either two or four letters, one at a time. They had to transform each letter mentally by moving or counting forward either two or four steps through the alphabet, then holding that outcome in working memory while transforming the next letter in the set; and b) series of number transformation trials: randomly selected single or double digit numbers in the range of 5-25 were substituted for the letters. Participants then had to transform those numbers by adding either the value 7 or 13. The results of this study showed that letter transformation was slower than number transformation, large transformations took more time than small ones, and transformation latency increased across mathematics anxiety groups. It also found that high-mathematics-anxiety participants spent more time transforming the letters and numbers and had lower accuracy in the tasks than did the low- and medium-anxiety groups. This implies that there is a mathematics-anxiety-related difference in the processing of information through working memory. Therefore, the results from both of
these studies lead to the conclusion that students with high mathematics anxiety are displacing use of their valuable limited working memory resources by displaying anxiety whenever they perform a mathematics task. In such an analysis, working memory would suffer the brunt of the mathematics anxiety effect because of the displacing impact of inner-worries and self-doubts that are reported by mathematics-anxious individuals (Ashcraft & Moore, 2009). These inner worries and doubts consequently interfere with the student’s working memory ability, which is critical to mathematics performance.

**Working Memory and Performance**

Working memory has been found to be important in many areas of academics, and extensive research has connected working memory to academic performance, specifically in mathematics. A student with poor working memory capacity will often struggle in the classroom with the acquisition of complex knowledge and skills by disrupting and delaying learning, therefore, leading to poor academic progress (Alloway, 2006). Children with working memory deficits have an extremely high risk of poor academic performance and demonstrate inattentive behavior and forgetfulness that disrupts learning (Alloway, Gathercole, Kirkwood, & Elliott, 2009). Teachers tend to attribute this to attentional and motivational issues, even though these students often show only variable evidence of attentional deficits (Alloway, 2006). Studies on working memory have shown a link with performance among primary aged students (Gathercole & Pickering, 2000) across grade levels (Gathercole, Pickering, Knight, & Steggman, 2004), and in college students (Seyler, Kirk, & Ashcraft, 2003). All three studies concluded that working memory is closely and negatively related to academic performance.

Gathercole and Pickering (2000) conducted a study of 83 (51 females, 32 males) children ages 6 and 7 to investigate whether working memory abilities are associated with achievements on standardized measures of reading, writing, and mathematics. Measures included a working memory battery, comprised of 13 tests designed to tap into three subcomponents of working memory including a) phonological loop (retains acoustic and verbal material), b) visuo-spatial memory (stores and manipulates visual and spatial information), and c) central executive (attention control center). This battery also included the *National Curriculum Assessments* (teacher assessments that judged children’s performance across contexts and tasks/tests – reading, writing, and mathematics). Results found that children with low levels of curriculum attainment showed marked impairments on measures of central executive function and of visuo-
spatial memory in particular. This suggests that complex working memory skills are closely related to children’s academic progress within the early years of school.

Gathercole et al. (2004) conducted a study that looked at the relationship between working memory skills and performance on national curriculum assessments in English, mathematics, and science among 40 children aged 7 (19 males, 21 females) and 43 children aged 14 (18 males, 25 females). The measures used in the study included Key Stage Assessments (measured level of achievement), Working Memory Test Battery for Children (included two central executive function and phonological loop function tests), and the younger group also completed the Children’s Test of Nonword Repetition (measured phonological loop function). Results found close associations between children’s scores on working memory measures and their national curriculum assessments. In other words, the children who performed poorly on the assessment had poor working memory. Poor working memory capacity limits an individual’s ability to meet the demands of processing and storing and may lead to more errors.

Seyler et al. (2003) examined the basic process characteristics of simple subtraction by testing 26 undergraduate students on the basic facts of subtraction, the inverses of addition facts (0 + 0 up to 9 + 9). Assessments used in this study included a paper-and-pencil mathematics and test anxiety test (measured mathematics and test anxiety) and a subtraction task (included 100 basic subtraction facts). The results found that there was a gradual increase on response time up to 10 – n problems, but then there was a large increase in the reaction times beginning with 11 – n problems. Errors also jumped dramatically from 5% to the 10%-22% range. This dramatic change in performance suggests that the larger subtraction problems were solved by using strategies or procedures. To see if strategies were used more as the problems became larger, the study was repeated and after each trial the participants were asked, “How did you solve this problem?” The reported use of strategies was 3% for the smaller subtraction problems and 33% for the larger subtraction problems. From this, it was predicted that individuals with limited working memory resources will be disadvantaged.

To test this hypothesis, Seyler et al. (2009) tested simple subtraction in a dual test setting. Participants held two, four, or six random letters in working memory while performing the subtraction, and then were instructed to report the letters in serial order. A large significant decrease in performance was found among the larger subtraction problems, which were the problems that relied on strategies. There was more interference with letter recall for the low-
working-memory participants (56% error rate) than for the medium-working-memory (46% error rate) or the high-working-memory groups (31% error rate). These results agree with conclusions made by Ashcraft and Krause (2007) that simple subtraction is an arithmetic operation typically introduced in second grade; it has a substantial working memory component to it, especially because even adults continue to rely heavily on strategy based processing instead of memory retrieval. Strategy-based solutions are slower and more demanding on working memory, compared to memory retrieval that is fast. In other words, working memory becomes increasingly involved in problem solving as the numbers in mathematics problems grow larger. Therefore, the use of strategies makes it difficult for individuals already suffering from limited working memory.

**Mathematics Anxiety and Prevention/Interventions**

Since mathematics anxiety has not only been found in older students, but also in elementary students, prevention is critical. Detecting mathematics anxiety early on may be beneficial to counseling programs that help to reduce anxiety and negative attitudes towards mathematics and support the need for prevention programs (Begley, 2007). Working to prevent mathematics anxiety early on may help reduce feelings of mathematics anxiety that could form during adolescence. Bibliotherapy, a form of therapy that uses children’s literature in which the characters experience a similar trauma, prompts discussion of these feelings, has been suggested as a prevention tool for students. Furner and Duffy (2002) suggest *Math Curse* (Scieska & Smith, 1995) to help students with mathematics anxiety. Teachers can also play an important role in preventing mathematics anxiety in students by making mathematics relevant to the students, letting students have some input, allowing for different social approaches to learning mathematics, and creating a variety of testing environments (Furner & Duffy, 2002).

A clear connection between mathematics anxiety, working memory, and mathematics performance has been well established, and it is important to address students’ needs in this area. Admiring the problem by continuing to study only the adverse effects of anxiety does not benefit the children like the interventions targeted at reducing anxiety. Ma (1999) quantified the potential improvement in mathematics achievement when mathematics anxiety is reduced. Such a reduction may be associated with an improvement from the 50th to 71st percentile in mathematics achievement for an average student highly anxious about mathematics. This suggests that if mathematics anxiety can be reduced, mathematics performance will increase.
Several interventions have been suggested to help students reduce mathematics anxiety, including alternate forms of testing such as journal writing, self-reflections, and group testing (Furner & Duffy, 2002; Steele & Arth, 1998), recognizing when the anxiety begins and learning to cope with it (Tobias, 1987), a classroom based intervention designed to reduce memory-related failures (Alloway, 2006), better teaching practices, encouraging, and creating a comfortable atmosphere (Jackson & Leffingwell, 1999), and relaxation techniques (Gregor, 2005). These interventions are helpful tools for teachers, but they do not directly address the working memory component of the problem.

Until recently, many did not believe that deficient working memory ability could be remedied. However, recent studies have proposed that working memory can in fact be improved. Because working memory is such a significant aspect in academics, and the use of evidence-based interventions is so important in today’s educational environment, researchers are exploring approaches and direct instructional programs that focus on improving working memory. Because mathematical performance is so important in schools, various working memory interventions have been implemented with the purpose of improving mathematical ability.

Turley-Ames and Whitfield (2003) performed three experiments examining how certain kinds of strategy training influenced working memory performance among undergraduate students. In a pretest-posttest design, all participants completed two versions of a working memory span measure, and half of the participants received strategy instructions prior to the posttest. Measures used in this study included an operation span test (assessed working memory span), and the Nelson-Denny reading test (assessed vocabulary and reading comprehension). Results showed that participants with low working memory spans benefited the most from rehearsal strategy instruction versus semantic or imagery strategies. Other methods shown to help students’ learning and poor working memory capacity are to decrease the cognitive load processed by redesigning academic presentation methods (Gathercole, 2008; Sweller, van Merrienboer, & Paas, 1998), and by encouraging students to use memory aids as strategies to support memory (Gathercole, 2008). Teachers can be taught how to distinguish task failures due to working memory overload, monitor their students for these failures, and reduce or represent the information when necessary (Alloway, 2006; Gathercole, 2008).

However, these approaches are not practical because they do not allow for generalization across different academic situations (Yuan et al., 2006). Gains in working memory from strategy
training often do not extend to varied learning conditions that children encounter daily (Holmes, Gathercole, & Dunning, 2009a). Some researchers are concerned that there is little evidence that training working memory in children actually leads to significant increases in performance (Turley-Ames & Whitfield, 2003). While there is certainly some reason to be skeptical about such approaches, new evidence-based interventions that directly target working memory capacity and skill have now been developed, refined, and proven to be effective.

Cogmed, a highly researched, computerized working memory training program, is an intensive working memory intervention designed to increase working memory through a sustained period of practice on activities that challenge working memory (Cogmed, 2006). Cogmed’s program, RoboMemo®, is composed of ten exercises, which include verbal, visuospatial, and numerical tasks. A robot guides program users through all tasks and reads letters or digits during the exercises. Participants respond to the program by clicking on the computer screen, and the program automatically adjusts the difficulty level to match the working memory ability of the individual. This program has helped improve working memory in individuals who have suffered from ADHD (Klingberg, et al., 2002; Klingberg, et al., 2005; Holmes et al., 2009b), have suffered from a stroke (Westerberg, et al., 2003), and individuals who have low working memory functioning (Holmes et al., 2009a). According to Cogmed (2006), increased working memory performance is seen in 80% of individuals who complete the training.

Klingberg et al. (2002) conducted a study to examine if attention, a working memory component, could be improved in children with ADHD between ages 7 and 15. In a double-blind placebo controlled design, 7 children with ADHD (1 female, 6 males) were assigned to the treatment group and 7 children with ADHD (2 females, 5 males) were assigned to the control group. Measures in this study included Raven’s Colored Progressive Matrices (measured prefrontal functioning and cognitive ability), the Stroop task (measured impulsivity), and an infrared camera (measured motor activity level). The treatment group participated in the cognitive training program (at least 20 minutes a day, 4-6 days a week, for 5 weeks) and the control group participated in a similar program (difficulty level was not adjusted and less than 10 minutes a day). Results showed that all the children in the treatment group improved. The computerized working memory training gradually increased the amount of information that the students could keep in working memory. Klingberg et al. (2002) repeated this study with 4 male
adults (ages 22-29) without ADHD. The results were similar to what was found with the children diagnosed with ADHD. This not only suggests that working memory can be improved, but also that a deficit in working memory is not necessary for improvement to occur.

Because of the evidence that working memory deficits can be effectively addressed, Holmes et al. (2009a) examined the educational significance of an adaptive program (Cogmed) in 22 children (12 males, 10 females) compared to 20 participants (15 males, 5 females) who completed a non-adaptive program. They wanted to determine whether improvement of working memory function was enough to overcome learning difficulties connected to poor working memory performance. In the 6-week study, the participants that completed the adaptive, working memory training improved their working memory scores to age-appropriate levels. This study provides the first demonstration that academic insufficiencies and learning difficulties can be improved, and possibly overcome, through intensive working memory training. Additionally, at the six-month follow-up, the students that completed the adaptive training showed a significant gain in their ability to follow spoken directions and in their mathematical reasoning scores (Holmes et al., 2009a).

In conclusion, significant relationships have been found between mathematics anxiety, working memory, and mathematics performance. As mathematics anxiety increases, an individual’s working memory is compromised (Ashcraft & Kirk, 2001) due to ineffective mental resource allocation. If an individual has a compromised working memory, mathematics performance will in turn be negatively impacted (Gathercole & Pickering, 2000; Gathercole et al., 2004; Seyler et al., 2003). From this body of research, a negative association has also been found between mathematics anxiety and mathematics performance (Ashcraft & Moore, 2009; Ma, 1999; Zakaria & Nordin, 2008; Mazzone et al., 2007). In order to increase mathematics performance and decrease mathematics anxiety, working memory deficits must be addressed. Therefore, the present study seeks to complement and extend the research completed by Holmes et al. (2009a) by reexamining the effects of Cogmed’s working memory training on students with mathematics anxiety. This study will investigate if Cogmed’s computerized, evidence-based training program can improve the working memory performance, mathematical performance, and consequently reduce levels of mathematics anxiety among a group of urban elementary school students. Findings from this study will help to determine the usefulness of computerized, cognitive training as a working memory and mathematical anxiety intervention. It is
hypothesized that this training will not only improve the students’ current working memory ability and mathematical performance, but also alleviate the feelings of tension and anxiety that are experienced with mathematics anxiety.
Research Design

Participants:
Participants were 16 third, fourth, fifth, and sixth grade elementary students from an urban district of a state in the Midwest. Participants ranged in age from 7-11. All students that participated in summer school through this school (grades 3, 4, 5, 6) were invited for participation. Informed consent was signed by all participating children’s parents or legal guardians before beginning the study. Child assent was also obtained from the students.

Materials:
Participants were asked various demographic questions. The students also received tests of working memory, mathematics performance, and a mathematics anxiety questionnaire that is described below.

Demographic information. The information sheet asked for age, gender, and year in school. This information was used to examine developmental differences in several areas of mathematics.

Mathematics anxiety. For this study mathematics anxiety was defined as a feeling of tension and nervousness that interferes with the manipulation of numbers and solving of mathematical problems. This was assessed by the Mathematics Anxiety Rating Scale - Elementary (MARS-E; Suinn, et al., 1988), which is a 26-item measure that is used to assess mathematics anxiety in upper elementary students (grades 4-6). The items on the rating scale represent mathematical situations that children would experience both inside and outside of the classroom. Students were expected to circle the rating that best represents their level of anxiety for each situation. The items are based on a 5-point Likert scale. The responses range from “not at all nervous” to “very, very nervous.” The value 1 is assigned to “not at all nervous” while the value 5 is assigned to “very, very nervous” and when the values are added scores range from 26 to 130. Therefore, higher scores are associated with greater mathematics anxiety. The MARS-E has high internal reliability of .88.

Working memory. For this study working memory was defined as the capacity and ability to simultaneously process and store information and was assessed by the Digit Span (Forward and Backward) and Letter-Number Sequencing subtests of the Wechsler Intelligence Scale for Children-Fourth Edition (Wechsler, 2003). These are measures used to assess working memory in children ages 6 to 16. In Digit Span Forward, the child repeats numbers in the same
order that the presenter reads them aloud. In Digit Span Backward, the child says the numbers backwards from what the presenter reads aloud. With Letter-Number Sequencing the child is read a sequence of numbers and letters and has to recall the numbers in ascending order and the letters in alphabetical order. For all three subtests, 1 point is given for each correct sequence and 0 points are given for each incorrect sequence. Digit Span and Letter-Number Sequencing have high test-retest reliability, .81 and .75 respectively (Williams, Weiss, & Rolphus, 2003).

**Mathematics performance.** For this study mathematics performance was defined as how well one performs on mathematical tasks that are measured by the Calculation subtest from the *Woodcock-Johnson Psychoeducational Battery – Third Edition* (WJ-III; Woodcock, et al., 2001). Calculation measures students’ mathematical achievement levels. This test is suitable for people ages 2 and up and has a reliability of .86 (Schrank, McGrew, & Woodcock, 2001).

**Cogmed.** RoboMemo® (Cogmed, 2006) is a multimedia, computerized training program for Windows designed to improve working memory in school-aged children, ages 7 and up. It requires participation for approximately 30 minutes every weekday for five weeks. The software guides the child through multiple rotating exercises each day. Cogmed was provided on a CD and installed on the school’s computers. It has been found that approximately 80% of individuals who complete the Cogmed training will experience benefits (Cogmed, 2006).

**Procedures:**

This study followed a pretest-posttest design. After the principal’s approval, the parents or legal guardians of the elementary students were presented with a letter of consent that provided a description of the study and requested permission for the students to participate in the assessments of mathematics anxiety, working memory, mathematics performance, and the working memory training program (see appendix A). Child assent was also obtained (see appendix B). Once permission was acquired, the researcher began to administer pretest measures (MARS-E and selected subtests of WISC-IV and WJ-III). Each measure was marked with individual identification numbers in order to offer confidentiality. The title on the MARS-E was covered in order to prevent any undesired emotions that could arise with the word “anxiety.” The directions and questions of the MARS-E were read aloud by the examiner while the students followed along. All testing was conducted by the researcher and graduate students trained in test administration. The testing session lasted approximately 30 minutes for each child. The students
were also told that there was no penalty for any survey or subtest that was handed in blank or unfinished.

The intervention occurred over a 5-week period and the students used Cogmed’s working memory training tool for 30-45 minutes a day, Monday through Friday. Sessions were monitored by the researcher to assist students with technical difficulties and to monitor the progress of the training sessions. The examiner observed the training sessions daily, and completed a standard treatment checklist to ensure treatment fidelity.

Post-test data was collected after the completion of the intervention. At that time, the experimenter and fellow graduate students reassessed the students on levels of mathematics anxiety (MARS-E), working memory (WISC-IV), and mathematics performance (WJ-III).
Results

The present research study attempted to answer the following questions respectively:

**Hypothesis 1:** Mathematics anxiety would negatively correlate with working memory and mathematics performance and that working memory would positively correlate with mathematics performance.

**Hypothesis 2:** Participation with Cogmed would result in reduced mathematics anxiety and increase working memory and mathematics performance among the elementary students.

**Hypothesis 3:** Students in the older grades would have greater gains in working memory and mathematics performance and greater reductions in mathematics anxiety than students in the lower grades.

Pearson correlation coefficients were run to measure the correlation between mathematics anxiety, working memory, and mathematics performance. Paired samples t-test were run to evaluate if ratings of mathematics anxiety would decrease and scores of working memory and mathematics performance would increase after the intervention. Analyses of variance (ANOVA) were also run to determine differences in mathematics anxiety, working memory, and mathematics performance, in terms of grade. General frequency statistics were calculated for the demographic information (see Table 1).
Table 1 General Frequency Statistics

<table>
<thead>
<tr>
<th>Gender</th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid</td>
<td>Female</td>
<td>11</td>
<td>68.8</td>
<td>68.8</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>5</td>
<td>31.3</td>
<td>100.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>16</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Age</th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid</td>
<td>7.00</td>
<td>2</td>
<td>12.5</td>
<td>12.5</td>
</tr>
<tr>
<td></td>
<td>8.00</td>
<td>3</td>
<td>18.8</td>
<td>18.8</td>
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<td></td>
<td>9.00</td>
<td>3</td>
<td>18.8</td>
<td>18.8</td>
</tr>
<tr>
<td></td>
<td>10.00</td>
<td>4</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>11.00</td>
<td>4</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>16</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Grade</th>
<th>Frequency</th>
<th>Percent</th>
<th>Valid Percent</th>
<th>Cumulative Percent</th>
</tr>
</thead>
<tbody>
<tr>
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<td>4</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>4.00</td>
<td>4</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>5.00</td>
<td>5</td>
<td>31.3</td>
<td>31.3</td>
</tr>
<tr>
<td></td>
<td>6.00</td>
<td>3</td>
<td>18.8</td>
<td>18.8</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>16</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Test of Hypothesis 1

To test the first hypothesis that mathematics anxiety would negatively correlate with working memory and mathematics performance and that working memory would positively correlate with mathematics performance, Pearson Correlation Coefficients were run. A correlation between mathematics anxiety and working memory yielded $r (16) = -.400$, $p > .05$. A correlation between mathematics anxiety and mathematics performance yielded $r (16) = -.436$, $p > .05$. A correlation between working memory and mathematics performance yielded $r (16) = .580$, $p < .05$. The first hypothesis was partially supported because a significant correlation was
found between working memory and mathematics performance, but not between the other variables (see Table 2).

**Table 2**

*Pearson Correlation Coefficients for Mathematics Anxiety, Working Memory, and Mathematics Performance*

<table>
<thead>
<tr>
<th></th>
<th>Math Anxiety</th>
<th>Working Memory</th>
<th>Math Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Math Anxiety</td>
<td>Pearson Correlation</td>
<td>1</td>
<td>-.400</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.125</td>
<td>.091</td>
</tr>
<tr>
<td>N</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Working Memory</td>
<td>Pearson Correlation</td>
<td>-.400</td>
<td>1</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.125</td>
<td>.019</td>
</tr>
<tr>
<td>N</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>Math Performance</td>
<td>Pearson Correlation</td>
<td>-.436</td>
<td>.580*</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td></td>
<td>.091</td>
<td>.019</td>
</tr>
<tr>
<td>N</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.05 level (2-tailed).

**Test of Hypothesis 2:**

Paired sample t-tests were run to test the second hypothesis that participation in the working memory intervention, Cogmed, would reduce mathematics anxiety and increase working memory and mathematics performance among the participants. A paired samples t-test was conducted to evaluate whether the levels of mathematics anxiety reduced after the intervention. The results indicated that the mean mathematics anxiety ratings after the intervention (M = 106) were not significantly lower than the mean mathematics anxiety ratings before the intervention (M = 116), t (15) = 1.653, p > .05. A paired sample t-test was conducted to evaluate whether the levels of working memory increased after the intervention. The results indicated that the mean working memory scores after the intervention (M = 103) were significantly higher than the mean working memory scores before the intervention (M = 90), t (15) = -4.936, p < .05. A paired sample t-test was also conducted to evaluate whether the levels of mathematics performance increased after the intervention. The results indicated that the mean mathematics performance scores after the intervention (M = 127) were significantly higher than the mean mathematics performance scores before the intervention (M = 102), t (15) = -6.066, p <
The second hypothesis was partially supported because significant differences were found in working memory and in mathematics performance levels, but not in mathematics anxiety (see Table 3).

**Table 3**

*Paired Samples t-tests for Pretest – Posttest Measures of Mathematics Anxiety, Working Memory, and Mathematics Performance*

<table>
<thead>
<tr>
<th></th>
<th>Paired Differences</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error</td>
<td>Lower</td>
</tr>
</tbody>
</table>

**Test of Hypothesis 3:**

To test the third hypothesis that students in the older grades would have greater gains in working memory and mathematics performance and greater reductions in mathematics anxiety than students in the lower grades, one-way analyses of variance (ANOVAs) were conducted. The first ANOVA measured mathematics anxiety in terms of grade, F(3,12) = .881, p > .05; the second one measured working memory in terms of grade, F(3,12) = .091, p > .05; and the third was run between mathematics performance and grade, F(3,12) = 2.661, p > .05. No significant differences among grades were found for mathematics anxiety, working memory, or mathematics performance (see Table 4).
Table 4

**ANOVA Summary for Grades**

<table>
<thead>
<tr>
<th></th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Difference in Math Anxiety</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Between Groups</td>
<td>1304.784</td>
<td>3</td>
<td>434.928</td>
<td>.881</td>
<td>.478</td>
</tr>
<tr>
<td>Within Groups</td>
<td>5922.414</td>
<td>12</td>
<td>493.535</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7227.198</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Difference in Working Memory</strong></td>
<td></td>
<td></td>
<td></td>
<td>.091</td>
<td>.964</td>
</tr>
<tr>
<td>Between Groups</td>
<td>37.438</td>
<td>3</td>
<td>12.479</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Groups</td>
<td>1643.500</td>
<td>12</td>
<td>136.958</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1680.938</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Difference in Math Performance</strong></td>
<td></td>
<td></td>
<td></td>
<td>2.661</td>
<td>.096</td>
</tr>
<tr>
<td>Between Groups</td>
<td>1612.333</td>
<td>3</td>
<td>537.444</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within Groups</td>
<td>2423.417</td>
<td>12</td>
<td>201.951</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>4035.750</td>
<td>15</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Discussion

This study obtained mathematics anxiety, working memory, and mathematics performance scores from one urban elementary school in Ohio. Scores were analyzed from 4 third graders, 4 fourth graders, 5 fifth graders, and 3 sixth graders totaling 16 participants. The study began with 29 participants, but 13 of these participants did not complete at least 17 days of the Cogmed program, and therefore were excluded from the analyses. Since there was such a small sample size, a better representation of mathematics anxiety, working memory, and mathematics performance across third, fourth, fifth, and sixth grade should include a larger sample size from various school districts.

This study collected data on mathematics anxiety, working memory, and mathematics performance using a pretest-posttest design with 16 participants. The data produced from a Pearson Product Correlation confirmed a significant correlation between working memory and mathematics performance, but not between mathematics anxiety and working memory or between mathematics anxiety and mathematics performance. The analyses indicated that there was a significant correlation between working memory and mathematics performance. This suggests that students who have higher working memory capacities are more likely to have higher scores in mathematics performance. This finding is consistent with the studies of Gathercole & Pickering (2000), Gathercole et al. (2004), and Seyler, et al. (2003). Although the analyses did not find a significant relationship between mathematics anxiety and working memory, a negative trend was still observed. Past research supports this notion that as mathematics anxiety scores increase, working memory scores will decrease (Ashcraft and Kirk, 2001). No significant correlation was found between mathematics anxiety and mathematics performance, but again a negative trend was obtained. Many authors have suggested that students that perform higher in mathematics are likely to be less anxious (Ashcraft & Moore, 2009; Ma, 1999; Zakaria & Nordin, 2008; Mazzone et al., 2007). Although significant findings were only found between working memory and mathematics anxiety, it is important that teachers are aware of the needs and capabilities of the students with different mathematics anxiety, working memory, and mathematics performance levels when designing teaching strategies for them.

In addition to the correlation results provided, paired sample t-tests confirmed a significant difference in working memory and mathematics performance scores, but were unable
to confirm significant differences in mathematics anxiety. It was surprising that there were not significant differences in mathematics anxiety scores after the intervention considering how strongly past research supports the correlations of the variables. Although mathematics anxiety scores were not found to be significantly lower after the intervention, 63% of the participants still saw reductions in mathematics anxiety levels.

In addition to these findings, data produced from an ANOVA found no significant differences and was unable to support the hypothesis that students in the older grades would have greater gains in working memory and mathematics performance and greater reductions in mathematics anxiety than students in the lower grades. Grade did not seem to be a good indicator to the amount of variable change expected. These results may be partially due to such a small sample size. Measuring and evaluating younger student’s mathematics anxiety and mathematics performance over several years could provide useful information about the possible differences in levels from year to year. Administrators and teachers would be able to use this data as a resource to monitor and reduce students’ mathematics anxiety and mathematics struggles from grade to grade.

Although this study was unable to support all of the hypotheses regarding mathematics anxiety, it does provide additional research in mathematics anxiety with a younger population. Teachers need to be aware of the effects of anxiety on students’ achievement. They should make an effort to lessen anxiety on these students. Teachers should develop strategies that help highly anxious students. Woodard (2004) suggested the following techniques for students: (a) create an environment in which students do not feel threatened and are comfortable, (b) use cooperative grouping. This helps students understand that others struggle with some of the same problems, (c) teach at a slow pace. This aids students in comprehending the material better, and (d) provide extra sessions and tutoring so that no one is left behind because they do not understand a concept. The combination of these efforts can help reduce mathematics anxiety in students.

Future Research

This study has shown that relationships do exist among mathematics anxiety, working memory, and mathematics performance. It has also shown how these variables change after receiving a 5-week working memory intervention. Researchers should now examine larger samples from more diverse populations. They should also consider investigating the mathematics anxiety levels of parents. This might provide added insight into the development of mathematics
anxiety among young children. The author also proposes using curriculum based measure progress monitoring tools with evidenced-based intervention because they are more sensitive to change than the measures used in this research. Since this study focused on the areas of mathematics anxiety, working memory, and mathematics performance, the author believes that further exploration of the links between mathematics anxiety, working memory, mathematics performance, and motivation in mathematics would make significant contributions in this area. The author suggests conducting a longitudinal study that follows the same participants from third grade to sixth grade. Lastly, the author recommends conducting a randomized controlled trial (RCT) study or a regression discontinuity study. This could provide more insight and could be valuable to the implementation and modification of instructional strategies within the classroom and act as a resource when creating or modifying mathematics curriculum.
References


and educational attainment: Evidence from National Curriculum Assessments at 7 and 14 years of age. *Applied Cognitive Psychology, 18*, 1-16.


Appendices

A. Parent/Guardian Consent Form

B. Student Consent Form
Appendix A

Parent/Guardian Consent Form

I. _______________________, have an understanding of the purpose, procedures, and my parental rights in regards to the intervention study that will be conducted at Dayton View Academy. I have contacted or will contact the Primary Investigator or Project Director if I have any concerns or questions regarding my son’s or daughter’s participation in the study or the intervention.

☐ I give permission for my child, ________________________, to participate in the intervention study. I understand that I can contact the Primary Investigator regarding my child’s general progress at any time. I also understand participation is completely voluntary and that my child may withdraw from the intervention study at any time without negative consequences.

________________________________________  __________________________
Parent/Guardian Signature                     Date

By signing above, I acknowledge that I am 18 years or older.
Appendix B

Student Consent Form

I am conducting a study to see if a computer game can help students better remember information and improve their skills in math. It is my hope that if you choose to be in the study that you will learn these skills and do better in school. If you agree to be in the study, you may have to leave class for some testing and for 30 minutes each day for five weeks. During this time, you will work on the computer game. At the end of the five weeks, there will be a few more tests. All testing is just to see what you know and will not affect your grades. If you have any questions before, during, or after my study, you can ask them. If you decide you do not want to finish the study, you can ask to stop.

If you sign this paper, it means that you have read this and that you want to be in the study. If you don’t want to be in the study, don’t sign this paper. Being in the study is up to you, and no one will be upset if you don’t sign this paper or if you change your mind later.

Your signature: __________________________________________Date __________

Your printed name: __________________________________________Date __________