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The Effect of Computerized Cognitive Training on the Working Memory and Mathematics Achievement of Low Achievers

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by

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We hereby certify that this dissertation, submitted by Shalette Ashman-East, conforms to acceptable standards and is fully adequate in scope and quality to fulfill the dissertation requirements for the degree of Doctor of Philosophy.

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An Abstract of a Dissertation Submitted to Nova Southeastern University in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy.

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Computerized cognitive training is recognized as an appropriate tool in enhancing working memory in individuals with and without physical limitations. Previous researchers have examined the application of computerized cognitive training in stroke patients, children suffering from ADHD, and older adults. Presently, there is a lack of controlled studies regarding computerized cognitive training in low-achieving primary school students. The goal of this study was to examine the interactions among working memory, computerized cognitive training and academic achievement. Specifically, the study sought to determine whether low-achieving primary school students would significantly improve their mathematics achievement (as measured by the Grade Four Literacy Test) and working memory capacity (as measured by the *Automated Working Memory Assessment*) through computerized cognitive training on working memory. A random pre-test post-test control-group experimental study was conducted to test the research hypotheses. The experimental group received progressive computerized working memory training. The control group received basic computerized working memory training. Training for both groups of student was conducted the same time each day by the class teacher at the participants' school. The duration for practice was one hour per day, five days per week for five weeks.

The working memory capacity of the experimental group was compared to the control group. Both experimental and control groups subjects showed improvements in working memory scores from the baseline pre-test to the post-test. Analysis of the multivariate tests suggests that there was significant difference (Wilks Lambda $F = 2.880$, $p = .045$) between the group receiving progressive computerized working memory training compared to the group receiving basic computerized working memory training. The mathematics achievement of the experimental group was compared to the control group immediately after completing training. Both the experimental and control group students showed improvement in post training mathematics scores. However, the difference between control and experimental group improvement was not significant ($F = 2.719$, $p = .085$). The end-of-term mathematics (six weeks after completing training) scores of the experimental group was compared to the control group. Both the experimental and control group students showed improvement in their end-of-term mathematics scores. However, the difference between control and experimental group improvement was not significant ($F = 2.719$, $p = .085$).

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Chapter 1

Introduction

Throughout life, people engage in the process of solving cognitive problems. Therefore, it is imperative that intrinsic cognitive skills function well in order for individuals to efficiently and effectively execute cognitive processes (Gathercole, Pickering, Knight & Stegman, 2003). Neisser (1967) defined cognition as "all processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used" (p.4). In addition to other systems, it is important for individuals to have an excellent working memory to temporarily hold information while simultaneously conducting the actions necessary to execute the requisite cognitive processes. To date, there are a number of information processing models. However, the multi-store model proposed by Atkinson and Shiffrin (1968) is widely accepted (Driscoll, 2005; Schunk, 2008). In this model, memory is hypothesized as having three stages in the following order: sensory register, short-term store, and long-term store. Atkinson and Shiffrin hypothesized that information that made it through the sensory register (via the senses) is transferred to a unitary short-term store for further processing. They theorized that information held in short-term store is either strengthened by rehearsal or lost. Items strengthened by rehearsal are subsequently sent to long-term store for permanent storage.

A tripartite working memory model (Figure 1) was proposed by Baddeley and Hitch (1974) as an alternative to Atkinson and Shiffrin's (1968) unitary short-term store. This alternative model is widely accepted in cognitive psychology, neuroscience and developmental psychology (Andrade, 2001). Baddeley (1986) described the multiple-component working memory model as consisting of a supervisory system (the central executive), and temporary memory systems. Baddeley (1996)'s temporary memory systems include a phonological loop, and a visuospatial sketchpad. Baddeley (2000) revised his model to include a third temporary storage component called an episodic buffer.

The central executive is hypothesized as performing a number of managerial functions such as directing the actions of the phonological loop and the visuospatial sketchpad, focusing and switching attention, and triggering images in long term memory (Baddeley & Logie, 1999). Baddeley (1986) portrayed the phonological loop as consisting of a short-term phonological store and an articulatory rehearsal component. The phonological store is described as being responsible for temporarily holding information in speech-based form. The articulatory component is depicted as being responsible for rehearsing and storing verbal information from the phonological store. The visuospatial sketchpad is theorized as being used to temporarily store information in a visual form (Logie, Zucco & Baddeley, 1990). The main responsibility of this episodic buffer is to connect information across the other components of working memory.

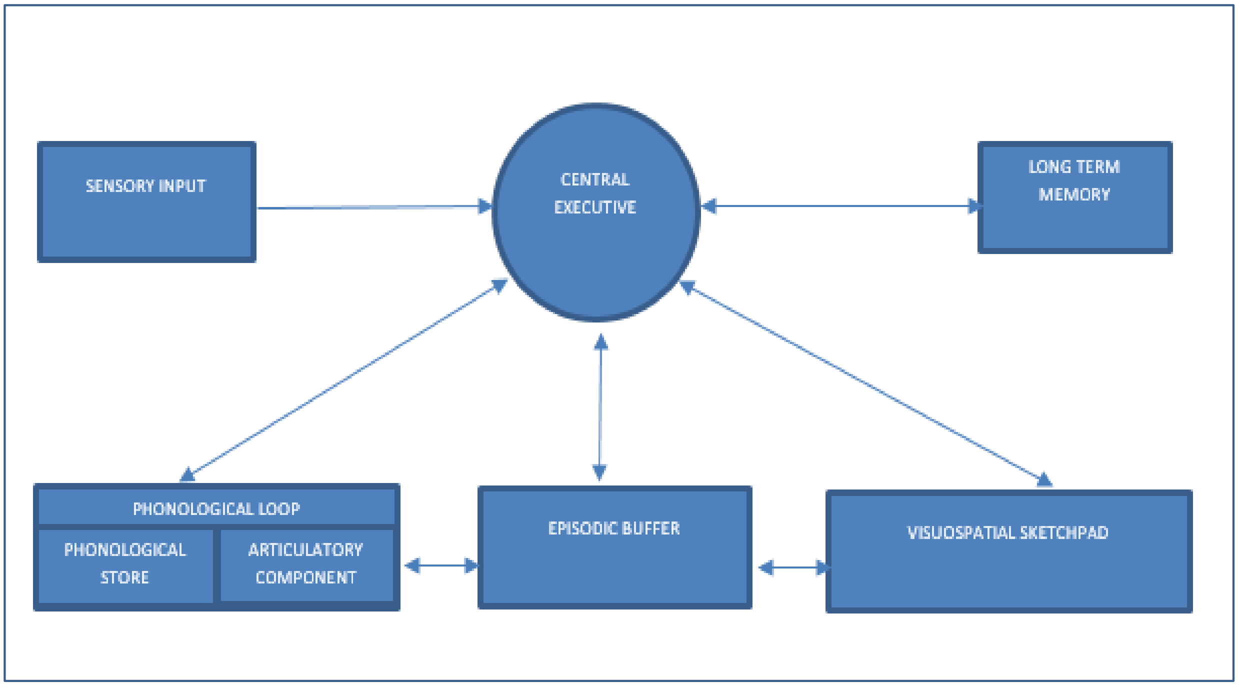

Figure 1. Working Memory Model. Adapted from Baddeley 2000

The connection between working memory and academic achievement is well-established (Gathercole & Alloway, 2008). However, research conducted by Alloway, Gathercole, Kirkwood and Elliott (2009) suggested that individuals have varied working memory capacity. This variance is critical, as working memory capacity is closely associated with learning abilities (Gathercole & Alloway, 2008; Gathercole, Pickering, Ambridge & Wearing, 2004). Research suggests that learners suffering from working memory deficit may have difficulty learning as a result of loss of information through overload or decay (Anderson & Lyxell, 2007). Research also suggests that working memory plays an integral role in mathematics and is vital for problem solving (Gathercole et al., 2003; Passolunghi & Siegel, 2004; Zheng, Swanson & Macoulides, 2011). In addition, research conducted by Pelavin and Kane (1990) showed that there is a direct correlation between success in high school mathematics and post-secondary school. Therefore, without appropriate intervention, working memory deficit in children could affect their learning and may lead to them being low achievers (Reis & McCoach, 2000).

Low achievers can be described as poor academic performers who typically achieve less than the average student (Hargis, 2006; Gresham, MacMillan & Bocian, 1996). There are a number of factors which impact students and influence their academic achievement (Balfanz & Byrnes, 2006; Gottfried, 2010; Madyun & Lee, 2010; Stotsky, 2010). These variables include, but are not limited to: (a) socioeconomic status (SES), (b) academic factors (such as the curriculum, school leadership, and teachers), and (c) personal factors (such as feelings of not belonging, self-efficacy, health issues, depression, intrinsic motivation, and working memory) (Balfanz & Byrnes, 2006; Gottfried, 2010; Madyun & Lee, 2010; Stotsky, 2010; McCoach & Siegle, 2001). While it is difficult to change some of the factors influencing academic achievement, empirical evidence suggests that some factors can be enhanced through intervention (Gottfried, 2010). For example, research suggests that brain training can enhance working memory. This enhancement is attributed to the idea of neuroplasticity which is the theory that an individual's brain can actually change as a result from training in a similar manner to how the muscles respond to exercise (Edlin et al., 2009; Klingberg et al., 2005; Sinha, 2005). The belief that working memory can be improved by training has influenced the development of computerized cognitive training programs purporting to help users with deficiencies in working memory capacity (Klingberg et al., 2005). Studies conducted by a number of researchers have demonstrated that computerized cognitive training programs have improved working memory capacity and attention in stroke patients, regular middle school students, children suffering from ADHD, healthy adults, and older adults (Brigman & Cherry, 2002; Holmes et al., 2009; Klingberg et al., 2005; Westerberg & Klingberg, 2007). Considering the possibility that an increase in working memory capacity could improve students' cognition and academic performance, it is worthwhile to examine if low-achieving primary school students could benefit from use of these programs. Hence, this study examined the interactions among working memory, computerized cognitive training and academic achievement.

Problem Statement

Working memory is a temporary storage system that allows users to simultaneously store and process information for brief periods (Baddeley, 2007). However, research conducted by Alloway et al. (2009) suggested that individuals have varied working memory capacity. For example, Alloway et al. screened over 3000 children; of this number, approximately 10% were identified as having very low working memory capacity. Research conducted on students in elementary, high schools, and colleges identified variables such as age and disease as factors impacting working memory capacity (Brigman & Cherry, 2002; Gunther, Schafer, Holzner & Kemmler, 2003). Unfortunately, children experiencing low working memory capacity are more likely to experience achievement problems as they tend to: (a) suffer from poor information recall, (b) experience problems in the development of emergent writing skills, and (c) perform poorly on national assessments (Alloway et al., 2009; Anderson & Lyxell, 2007; Gathercole et al., 2004; Gathercole & Alloway, 2008; Lee, Ng & Ng, 2009;

Watson, Bunting, Poole & Conway, 2005; Gathercole & Pickering, 2000; Gathercole et al., 2004).

While having an optimal working memory is integral to overall academic achievement, its importance to mathematics achievement is indicated (Passolunghi & Siegel, 2004; Zheng et al., 2011). LeBlanc and Weber Russell (1996) showed a definitive correlation between the ability of working memory to handle load and mathematics achievement. The importance of working memory to mathematics achievement was also supported by the results of a study conducted by Passolunghi and Siegel (2004b) that showed the connection between the ability to reduce the accessibility of irrelevant information in memory and mathematics problem solving. The hypothesis of working memory deficit in children experiencing mathematical difficulties was further strengthened by a study conducted by Passolunghi and Siegel (2004). In this study, an impairment and lower recall of pertinent information in working memory tasks was observed in children experiencing difficulties with mathematics. Computerized cognitive training has been shown to enhance working memory (Brigman & Cherry, 2002). Although computerized cognitive training has been shown to improve working memory, its value in improving the academic achievement of low achievers in a primary school setting has not been established.

Goals

The goal of this study was to determine whether low-achieving primary school students would significantly improve their working memory capacity (as measured by the *Automated Working Memory Assessment* (Alloway, 2007)), and mathematics achievement (as measured by the Grade Four Literacy Test) through computerized cognitive training on working memory. A random pre-test post-test control-group experimental study was conducted to test the research hypotheses. The following research questions were addressed in this study:

1. What impact will computerized cognitive training have on the working memory capacity of fifth grade primary school low achievers?
2. If working memory capacity significantly improved, to what extent will this improvement affect the mathematics achievement of fifth grade primary school low achievers?

Relevance and Significance

As discussed, the incidence of low working memory capacity in children is significant (Alloway et al., 2009). This is concerning as research has shown that children experiencing low working memory capacity are more likely to encounter problems with achievement (Alloway et al., 2009; Anderson & Lyxell, 2007; Gathercole et al., 2004; Gathercole & Alloway, 2008; Gathercole & Pickering, 2000; Lee et al., 2009; Watson et al., 2005). Additionally, researchers theorized that students experiencing problems with achievement could feel increasingly inadequate and lose their self-confidence (Anderson & Lyxell, 2007; McCall, Evahn, & Kratzer, 1992; Peterson & Colangelo, 1996). These students are also more prone to youth violence and have been linked to community and school aggression (Loeber & Farrington, 1998; Maguin & Loeber, 1996).

A number of computerized cognitive training programs such as Cogmed, Brainbuilder, Processing and Cognitive Enhancement (PACE), Audioblox and Earobics purport to improve working memory (Cogmed, 2010; Holmes, 2009; Klingberg, 2005; Sanchez, Mahmoudic, DiGiovanna, & Principe, 2009). Studies suggest that computerized cognitive training programs have improved working memory and attention in stroke patients, children suffering from ADHD, and older adults (Holmes et al., 2009; Klingberg et al. 2005; Westerberg & Klingberg, 2007; Brigman & Cherry, 2002). Therefore, the approach presented has a realistic chance of success. In addition, this study has potential theoretical and practical value which could extend beyond the identified subject population. Theoretically, it will contribute to the research on the interactions among working memory, computerized cognitive training, and achievement. Practically, it will explore new tools to assist low achievers and may prove useful in improving their academic achievement.

Barriers and Issues

The design and implementation of this study may have presented some issues. Mortality is an inherent threat to internal validity. The mathematics pre-test treatment interaction could have posed a problem, as the mathematics pre-test could have sensitized participants and thus influence the mathematics post-test scores (Gay et al., 2006).

Extraneous and intervening variables such as SES, personal and academic factors could confound this study. Therefore, a combination of random assignment and a pre-test post-test control group design was used to control sources of internal and external validity (Gay et al., 2006). In addition, the *Automated Working Memory Assessment* (Alloway, 2007) which is a valid and reliable instrument was used to measure changes in working memory for both the control and experimental groups.

Assumptions

Gay et al. (2006) describe assumptions as "any important fact presumed to be true but not actually verified" (p.83). The following were assumed:

1. Working memory is malleable and can be improved with practice (Brigman & Cherry, 2002; Edlin et al., 2009; Klingberg et al., 2005; Sinha, 2005).
2. Working memory is linked to academic success (Gathercole et al., 2004; Watson et al., 2005).
3. Working memory is measurable, and the instrument being used is a reliable instrument to do so (Daneman & Carpenter, 1980; Jarrold & Towse, 2006; Unsworth, Redick, Heitz, Broadway & Engle, 2009).
4. The study population is representative of the larger low achievement population.
5. Participants have not participated in previous computerized cognitive training.
6. Participants will make a real effort to complete the working memory training exercises.
7. Participants can use a personal computer.

Limitations

Creswell (2008) describes limitations as "potential problems with the study identified by the researcher" (p.207). The factors described below could have limited the results of this study. This study was focused on examining fifth grade low achievers. To accomplish this feat, all 30 students in the sole low achieving fifth grade class at a primary school in Kingston Jamaica were included in the study. Creswell (2008) endorses the inclusion of approximately 15 participants in each group in an experiment. However, despite this endorsement, this modest number of participants could potentially limit the result findings as statistical tests favor a larger sample size in order to decrease sampling error and ensure generalizability. Furthermore, two students were not able to complete the study due to unforeseen problems. This attrition altered the composition of the control group. This alteration could have potential negative impact on the significance of the research results.

Students participating in the study were all from a low socioeconomic background. This presented numerous challenges which negatively impacted students' engagement in the training activities, attention, social skills, and behavior. This in turn adversely affected session completion. In addition, the researcher was not blinded to the subject's group as there was a subtle difference between the user interfaces for the progressive computerized cognitive program and the basic computerized cognitive training program. The non-blinded nature of the researcher could have introduced some bias.

Delimitations

Individuals for this study were selected from a population of low achievers and were selected if they met the following criteria:

1. They were fifth grade low-achieving primary school students.
2. They stated their commitment to participate in pre-test, post-test and computerized training sessions.
3. They demonstrated mental acuity. Specifically, students who were diagnosed as mentally retarded or learning disabled were excluded from this study.

4. They indicated non-participation in previous computerized cognitive training programs.
5. They were not taking cognitive enhancement drugs.

Definitions of Terms

The following terms are defined in the interest of clarity.

Cognition

Neisser (1967) defined cognition as “all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used” (p.4).

Low achievers

Low achievers can be described as poor academic performers who typically achieve less than the average student (Hargis, 2006).

Neuroplasticity

Neuroplasticity is the theory that an individual’s brain can actually change as a result of training (Edlin et al., 2009).

Progressive Computerized Cognitive Training

Progressive computerized cognitive training involves increasing the difficulty level of the working memory tasks assigned to participants during the training sessions.

Short-term memory

Jarrold and Towse (2006) conceptualized short term memory as the ability to maintain information over a limited time.

Working memory

Working memory can be conceptualized as an active system that simultaneously holds and manipulate data. Jarrold and Towse (2006) defined it as “the ability to hold in mind information in the face of potentially interfering distraction in order to guide behaviour” (p. 39).

Summary

In Chapter 1 the goal of the study and the concepts of working memory and low achievement were introduced and discussed. In addition, a population of persons suffering from low achievement were identified as the specialized population of low achievers for this study. It appears that individuals suffering from low achievement are likely to experience problems with working memory. This is significant, as working memory impacts cognition and is critical for mathematics problem solving. Studies suggest that training the brain may improve working memory in the same manner that it does the muscles. This belief has led to the development of numerous computerized cognitive training programs purporting to enhance working memory capacity.
The goal of this study was to determine whether low-achieving primary school students would significantly improve their working memory capacity (as measured by the *Automated Working Memory Assessment* (Alloway, 2007)) and mathematics achievement (as measured by the Grade Four Literacy Test) through computerized cognitive training on working memory. The study addressed two pertinent questions, what impact will computerized cognitive training have on the working memory capacity of fifth grade primary school low achievers, and if working memory capacity significantly improved, to

what extent will this improvement affect the mathematics achievement of fifth grade primary school low achievers?

A review of the literature is presented in Chapter 2. This chapter describes computerized cognitive training. The need for the investigation of computerized cognitive training in a population of low achievers is also established. Chapter 2 also looks at the structural components of working memory and explores its role in cognition. In addition, the chapter examines the concept of low achievement and intervening variables which influences same are discussed. The impact of working memory on mathematics and general academic achievement are reviewed.

A detailed step-by-step description of the design utilized in this study is discussed in Chapter 3. A restatement of the research questions and hypotheses are presented. This is followed by a discussion of the independent, dependent and intervening variables. Next, a detailed description of the instruments, participant selection and assignment process are presented. The testing methods, analysis, ethical considerations, and resources are then examined.

Data analysis and findings are covered in Chapter 4. The working memory of the group receiving progressive computerized working memory training was compared to the group receiving basic computerized working memory training immediately after training using a Repeated Measures Multivariate Analysis of Variance *(MANOVA)*. The mathematics achievement of the group receiving progressive computerized working memory training was compared to the group receiving basic computerized working memory training using a Repeated Measures *MANOVA*. The findings, limitations, suggestion for future research, and recommendation are presented in Chapter 5.

Chapter 2

Review of the Literature

Introduction

This study examined the efficacy of computer assisted cognitive training on the working memory and mathematics achievement of low achievers. Section one of the review of the literature examined the concept of low achievement. In this section, low achievement is defined and intervening variables which influences same are discussed. More specifically, the section examines SES, academic and personal factors which impact students and influence academic achievement. These factors are investigated in order to determine the extent to which they impact students and influence achievement.

Section two describes working memory and examines its impact on academic achievement. Here, the primary model used to explore the role of working memory in cognition is discussed. The examination of working memory is undertaken to establish a foundation in the literature regarding what we know and what remains unknown about working memory. In addition, issues such as the impact of working memory on academic achievement are reviewed.

The third section builds on section two and examines the impact of working memory on mathematics problem solving. This examination of the impact of working memory on mathematics is undertaken in an attempt to determine the extent to which working memory affects mathematics achievement. In addition, this serve to provide a solid theoretical foundation for the focus on mathematics in this study. Section four describes the use of computer assisted cognitive training programs on working memory.

Studies dealing with the impact of computerized cognitive training programs on the working memory of adults and children will be highlighted. In addition, studies discussing the impact of working memory on specific cognitive tasks such as information recall and processing speed are discussed. These studies were reviewed with a view to determine if use of these programs enhances working memory and could potentially help low achievers.

Low Achievement

Low achievers can be described as poor academic performers who typically achieve less than the average student (Hargis, 2006; Gresham et al., 1996). In their study, McCoach and Sigle (2001) analyzed the responses of students on the five factors (attitudes toward school, attitude toward teachers, goal valuation, motivation, and general academic self-perceptions) of the *School Attitude Assessment Survey-Revised* (SAAS-R). Students ($n = 244$) comprising of 148 low achievers and 96 high achievers participated in this study. Analysis of the study revealed a statistically significant difference ($p < .001$) between low achievers and their counterparts on the factors of the SAAS-R. In addition, academic self-perception was shown to be the most important variable separating low achievers from their counterparts (McCoach & Sigle).

Researchers agree that the consequences of low achievement are harsh and far-reaching (Balfanz & Byrnes, 2006; Gottfried, 2010; Madyun & Lee, 2010; Stotsky, 2010). In addition to accounting for a large percentage of school drop-outs, there is also consensus that low achieving students typically go on to experience a higher level of underemployment and unemployment compared to their counterparts (Alexander, Entwisle & Dauber, 2003; Marks & Fleming, 1999). The following paragraphs examine some SES, academic and personal factors which impact students and influence academic achievement.

Socioeconomics Status and low Achievement

Socioeconomic Status can be conceptualized as a combination of education, income, and occupation (Demarest et al., 1993). The influence of SES on academic achievement is indubitable. Socioeconomic status impacts (a) readiness for school, (b) students' engagement in learning activities, (c) attention, (d) social skills, (e) literacy, (f) later school performance, (g) learning-related behavior problems, and (h) school attendance (Coley, 2002; Madyun & Lee, 2010; Morgan, Farkas, Hillemeier & Maczuga, 2008; Pianta & Stuhlman, 2004; Schunk, 2008).

The impact of SES on children's readiness for school is supported by the results of a study conducted by Coley (2002). Coley analyzed data obtained from the *Early Childhood Longitudinal Study*, Kindergarten Class of 1998-99 (ECLS-K). This data represented kindergarten to fifth grade students (*n* = 20,000) from 1,000 public and private schools. The researcher analyzed reading, mathematics and home reading data from 95% of the participants in order to determine school preparedness and approach to learning. Students whose primary language was not English as well as students who scored below a certain percentage on a language screening test were excluded from the analysis. Results of the study showed that children in lower SES groups exhibited lower reading skills compared to their counterparts. For example, only 39% of the children in the low SES households were able to recognize letters of the alphabet compared to 85% of children who were from higher SES households. In addition, there was a significant relationship between SES and children's understanding of the beginning sounds of words. Analysis of the data revealed that 51% of students from high SES households were proficient in understanding the beginning sounds of words compared to 10% of their counterparts. Thirty three percent of students in the high SES quintile were able to understand the ending sounds of words compared to only 3% of students in the lowest SES quintile. Although statistically small ($p < .5$), children in the highest SES quintile were more proficient in recognizing common words than their counterparts. Three percent of children from the highest SES quintile were proficient in reading words in context compared to 0.1% of children in the lowest SES quintile.

Analysis conducted by Coley (2002) also revealed that children in high SES groups exhibited higher numeracy skills compared to their counterparts. For example, 98% of the children in the highest SES quintile were able to recognize numbers and shapes compared to 84% of children in the lowest quintile. In addition, only 31% of students in the lowest SES quintile understood relative size compared to 77% of children from the upper SES quintile. Six percent of the children in the lower quintile were able to understand ordinal sequence compared to 39% of children in the highest quintile. One percent of children in the lowest SES quintile could add and subtract proficiently compared to 9% of children in the highest SES quintile.

In regards to home reading experience, analysis of the data revealed that high SES parents were twice as likely to read to their children compared to their counterparts (Coley, 2002). For example, only 36% of parents in the lowest SES quintile reported reading to their child every day compared to 62% of the parents in the highest quintile. In addition, 45% of children in the lowest quintile looked at picture books outside of school every day compared to 62% of students in the highest quintile.

Research of the literature also suggests that SES affects the performance of students in later years. Duncan et al. (2007) examined elements of school readiness and its influence on later school achievement. The researchers used a large scale data set of six longitudinal studies comprising children from the United States, Canada and Great Britain. A number of hypotheses were employed to examine the relationship between early academic skills, socio-emotional skills and later school achievement. Results of the regression results (standardized coefficients .05 to .53) suggest that students' readiness statistically predict future academic achievement (Duncan et al.,).

Empirical data supports the view that SES influences learning-related behavior problems. In a study conducted by Morgan et al. (2009) designed to: (a) determine the impact of socio-demographic and socioeconomic factors on children's susceptibility for learning-related behavior problems at 24 months, and (b) estimate the degree to which parents may influence children's behavior. Children (n = 5,522) were rated and analyzed on cognitive and physical skills while executing learning related tasks. In addition, children's and parents' socio-demographic and SES data were captured and analyzed. Based on regression analysis, it was demonstrated that parents who fell in the lowest quintile had the most negative relationship to parenting. For example, there was a significant association between (a) non-persistence ($p < 0.01$), (b) attentiveness ($p < 0.01$), (c) interest ($p < .05$), and (d) cooperation ($p < .001$) for mothers who fell in the lowest educational quintile.

Madyun and Lee (2010), suggested that female headed households were influential in determining the reading achievement of Black male students. Data from middle school students (*n* = 2,849) from a large Midwestern school district in the United States were analyzed. The researchers collected data from the standardized reading scores of white students (*n* = 1667) and black students (*n* = 1182) from the 2002 Metropolitan Achievement Test -7 (MAT-7). Students' demographic information and individual risk factors were obtained from the students' permanent records. In addition, socioeconomic data including female-headed households, poverty, and racial diversity were obtained from the U.S. Census. The researchers also collected neighborhood crime data from the local police department. Results of the hierarchical linear modeling analyses (-3.50 (1.23), $p < .01$) suggested that female-headed households negatively influenced the academic achievement of Black male students. Specifically, 21% of the black male students were labeled with special education status, which was more than twice the percentage of white students. "Black male students in special education turned out to be the lowest achievers" (Madyun & Lee, 2010, p. 440). This is important as an eighth of household are headed by single mothers (Kansas State Department of Education).

Students who attend school regularly are able to receive more hours of instructions compared to their counterparts. Unfortunately, students living in low SES household are more likely to be absent from school compared to students from high SES households (Rothman, 2001). Students displaying poor attendance are at an academic disadvantage as school attendance influences academic achievement (Gottfried, 2010). Gottfried utilized a comprehensive dataset (*N* = 332,924) of elementary and middle school students in the Philadelphia School District between 1994/1995 to 2000/2001. The dependent variable in this study was GPA, while days present, student demographics, and neighborhood characteristics were the independent variables. Three methodological approaches were used to evaluate the data. The first involved the assessment of achievement and attendance (days present), student demographics, and neighborhood characteristics. The effect sizes, per the standardized regression coefficient ranged from 0.24σ to 0.34σ. This suggested a correlation between school attendance and higher GPA. A lagged measure of achievement was introduced as a second approach to evaluating the attendance-achievement relationship. Results (coefficients on number of days present 0.010) of the lagged measure of achievement supported the findings of the baseline model.

However, despite the indubitable association between low SES and low academic achievement, research of the literature indicates that some low SES students are academically successful. For example, Milne and Plourde (2006) conducted a qualitative study on students who were achieving academic success despite living in low SES households. Second grade students (n = 6) participated in this study. Result of this ethnographic study revealed that none of these high achieving low SES students displayed factors characteristics of low SES homes. As a result of this knowledge, Milne and Plourde offer the recommendation that instead of looking at the correlations between SES and academic achievement, educational stakeholders should focus attention on the factors influencing success in schools.

Academic Factors and Low Achievement

Academic factors sometimes serve as obstacles that block the path of low achievers. Some factors shown to impede academic success include: (a) the curriculum, (b) school leadership, and (c) teachers. The Kansas State Department of Education reports that students who are exposed to an engaging and rigorous curriculum will be better prepared for success in post-secondary education. This is supported by the results of a study conducted by Stotsky (2010) designed to analyze the responses of English teachers (n = 400) in Arkansas Public Schools. These teachers were asked to identify texts assigned in standard and honors courses and the approaches used to teach students imaginative literature and literary nonfiction. The results of the analysis revealed an inconsistency in the content of the literature curriculum for students in standard or honors courses across grades nine to eleven. For example, of the 20 most frequently assigned major works of fiction, drama, and book length poems, only four had a high school readability level. In addition, majority of the 20 most frequently assigned titles appear in fewer than 10% of the 773 courses described in the survey. It was revealed that the textbooks did not increase in difficulty from grades nine to eleven. The researcher also highlighted weaknesses in the pedagogical approaches favored by English teachers in evaluating students' work. For example, instead of focusing on the plot, characters, style, and moral meaning of the novel *To Kill a Mockingbird*, the trial in the text was juxtaposed with Scottsboro trials or Jim Crow laws in the South.

In addition to being rigorous, curricula should be designed to give students opportunities to learn during self-study as well as during class. This is important, as the time students have available for self-study influences their academic achievement

(Schmidt et al., 2010). However, the time available for self-study is influenced by the design of the curricula (Torenbeek, 2012). For example, Schmidt et al. examined the timetables of each curriculum for medical students (n = 13,845). Results of the analysis (p = .14) suggested that the number of lecture hours scheduled in a curriculum negatively impacts the graduation rate. In addition, the number of lecture hours scheduled in a curriculum was shown (p = .04) to negatively impact the study duration.

Another variable impacting students' academic achievement is school leadership. The school leader, usually the principal, is integral as he or she is tasked with the responsibility of developing and implementing a comprehensive plan that best represents the school's vision. In addition, the leader is responsible for ensuring parent participation and student behavior (Kansas State Department of Education, 2006). Another important function of an effective leader is the selection and retention of effective teachers. This is important as effective teachers could serve to bridge the learning divide among students. Poulou (2007), advocated for the use of teachers who possess high self-efficacy. These teachers are characterized as possessing the belief that they can positively affect the academic achievement of their students (Schunk, 2008). They are perceived as more likely to persist with students compared to their colleagues. This means they are more likely to implement out-of-the-box strategies to influence learning (Schunk).

School reform which takes a multifaceted approach to improvement is relevant as there are numerous academic factors which affect students and influence their academic achievement. For example, Balfanz and Byrnes (2006), concentrated on a series of analyses that tracked the progress of four groups of students in mathematics through the 5th to 8th grade. Three schools made significant reforms including: (a) the implementation of research based curriculums, (b) subject specific teacher training and professional development, and (c) multi-tier teacher-student support. Logistic regression analyses were conducted to determine the impact of factors on students' ability to close the achievement gaps during middle school. Results of the analyses showed 27% of the students in the reformed schools catching up on the SAT-9 standardized test compared with only 19% of the students in the rest of the district ($p = 0.000$, $t = 7.311$, $df = 13696$). In addition, 33% of students in the reformed schools gained more than 10 state percentiles in the state-administered PSSA exam. This was 8% a difference significant at the .001 level ($p = 0.000$, $t = 8.167$, $df = 13003$) more than students in the district's other schools (Balfanz & Byrnes).

Personal Factors and Low Achievement

In addition to SES and academic factors, personal factors also play a significant role in academic achievement. These factors include but are not limited to: (a) feelings of not belonging, (b) self-efficacy, (c) health issues, (d) depression, (e) intrinsic motivation, and (e) working memory. For example, Langhout, Drake and Rosselli (2009) identified feelings of not belonging which they contend can be triggered by being identified with a certain social class as a personal factor worthy of probe. Langhout et al. conducted a study with students from an elite private liberal arts university. All students from the university were sent an email which requested that they complete a survey designed to assess their experiences at the university. Students ($n = 950$) completed the study. Results ($p < .05$) of the study suggested that poorer students are more likely to experience classism. In addition, they explained that classism "was negatively associated with school belonging and psychosocial outcomes, and positively associated with intentions to leave school without graduating" (p. 175).

Schunk (2008) conceptualized self-efficacy as a personal belief about what an individual is capable of doing. Researchers believe that constant academic failure could serve as the fuel to keep the fire of self-doubt alive in low achievers. This in turn could potentially put low achievers at risk to suffer from low self-efficacy. Researchers suggest that among other things self-efficacy affects: (a) career choice, (b) effort, and (c) task persistence (Schunk; Branch & Lichtenberg, 1987). Consequently, low achievers may fail to exert the requisite effort to successfully complete tasks compared to their counterparts.

The link between health and academic achievement is well documented. To test the relationship between dental problems and academic achievement, Seirawan, Faust and Mulligan (2012) examined 1495 elementary and high school students. The researchers compared the dental health data of the students to their academic and attendance data. They found that students with toothaches and inaccessible dental care had lower academic achievement and higher record of absenteeism compared to their counterparts. More specifically, they found that approximately 16% of students with toothaches missed school compared with 3% of those without toothaches ($p < .001$). In addition, almost 11% of the students who did not have access to dental care were absent from school compared to only 4% of their counterparts ($p < .001$). Researchers also opine that there is a close association between children experiencing hearing problems and academic achievement (Easterbrooks & Beal-Alvarez, 2012; Vernon, Raflman, Greenberg, & Monteiror, 2001). A report from the California Department of Education (1999) indicates that deaf and hard-of-hearing children graduate at grade 2.8 compared to tenth grade for their counterparts. The California Department of Education report also predicts that only 8% of deaf and hard-of-hearing students will graduate from college. In addition to problems relating to hearing and oral health, Chen, Bleything and Lim (2011) and Zebehazy, Zigmond and Zimmerman (2012) believe that children suffering from vision problems are likely to experience reading problems which could lead to low achievement.

The influence of intrinsic motivation on academic achievement is supported by the results of an analysis conducted by Gottfried and Gottfried (1996). The researchers examined the intrinsic motivation of academically gifted students (n = 20) and a comparison group (n = 79) in the Fullerton Longitudinal Study. Data from *the Children's Academic Intrinsic Motivation Inventory* (CAIMI) were analyzed. Results of the study showed highly significant effect $F(5, 91) = 3.63$, $p = .005$) for giftedness. In addition, the academically gifted students; reading F (1, 95) = 8.25, p = .005; mathematics F (1, 95) = 15.91, p < .001, social studies $F(1, 95) = 8.48$, p = .004; science F (1, 95) = 10.81, p = .001 had higher intrinsic motivation compared to their counterparts.

The Impact of Working Memory on Achievement

Atkinson and Shiffrin (1968), in their very popular multistore model presented memory as having three stages in the following order: sensory register, short-term store, and long-term store. They theorized that information that makes it through the sensory register (via the senses) is transferred to short-term store. They assumed that information making it to short-term store decays and disappears over a short period. However, they theorized that the decay period for information in short-term store is influenced by subject-controlled processes. One such process is rehearsal which serves the purpose of lengthening the time information stays in short-term store prior to being sent to long-term store for relatively permanent storage. Atkinson and Shiffrin's unitary short-term store was replaced by Baddeley and Hitch's (1974) multiple-component working memory model. The main conceptual difference between Atkinson and Shiffrin's short-term store and Baddeley and Hitch's multiple-component working memory model is in an individual's ability to conduct the dual process of holding data in mind while simultaneously performing other processes in order to complete some cognitive task (Andrade, 2001; Jarrold & Towse, 2006).

Overview of Working Memory

Repovs and Baddeley (2006) described the multi-component working memory model as consisting of "a central executive, two unimodal storage systems: a phonological loop and a visuospatial sketchpad, and a further component, a multimodal store capable of integrating information into unitary episodic representations, termed episodic buffer" (p. 5). The central executive is theorized to perform a supervisory role in working memory. It is also presumed to provide resources to the slave systems (Baddeley, 1986). The phonological loop consists of a short-term phonological store and an articulatory rehearsal component. The short-term phonological store is described as being responsible for temporarily holding information in speech-based form. However, this speech-based information is subject to rapid decay. The articulatory component supports the phonological store by rehearsing and storing verbal information from that component. The visuospatial sketchpad is theorized as being used to temporarily store information in a visual form (Logie et al., 1990). The visuospatial sketch pad includes the maintenance and assimilation of visual and spatial information and a means of refreshing it by practice (Wynn & Coolidge, 2010). Baddeley (2000) revised his model to include an episodic buffer. The episodic buffer is theorized to serve as a transient storage memory system for the central executive. The episodic buffer connects information across the other components of working memory. Research conducted by Gathercole et al. (2004) supports the tripartite model.

Because working memory involves holding information in the mind while simultaneously conducting other processes, tasks designed to measure working memory capacity are designed around the dual operation of holding and manipulating information (Daneman & Carpenter, 1980). These tasks are typically referred to as complex span tasks. Jarrold and Towse (2006) explained that complex span tasks usually involve individuals simultaneously processing and recalling a list of items. Items that are usually used in complex span tasks include digits, letters, words, shapes and so on. Processing actions executed on these items include reading, listening, counting, etc. Complex span tasks have good reliability and validity. Consequently, they are used not only in basic theoretical conceptions of working memory capacity but in more applied and clinical situations (Unsworth et al., 2009).

Working Memory and False Memory

Close association between individual differences in working memory and an individual's ability to learn are well established (Watson et al., 2005). Watson et al. conducted a study comprising two experiments with a cohort of undergraduates (n = 100) from the University of Illinois-Chicago. Their study suggested that individuals with low working memory capacity are more likely to experience false memories. Prior to conducting the experiments, participants were placed into high and low span groups based on the result of the scores on their working memory test.

Experiment one was designed to determine whether individual differences in working memory capacity made young adults susceptible to false memories. All participants were given a practice list of semantic associates at the outset of the experiment in order to familiarize them with the testing procedures. In addition, half the high and low spans were warned about the Deese-Roediger-McDermott (DRM) false memory paradigm. Except for the DRM false memory paradigm warning, the other half of the high and low spans received identical treatment to the warned participants. All participants were required to study 36, 16-word lists presented visually (via a projection screen). They were then tested for recall, and advised against guessing when trying to remember the words from each list. A series of two spans (high or low) and two warnings (present or absent) analyses of variance (*ANOVAs*) were performed on veridical recall, false recall of critical words, and other noncritical word intrusions. Results of experiment one revealed that high spans recalled more studied words (.49) compared to low spans (.44). In addition, warned participants recalled fewer studied words (.45) than non-warned participants (.48). Results of a two (span) x two (warning) *ANOVA* on veridical recall confirmed a main effect of span, ($F(1, 96) = 12.32$, $MSE = .006$), and a main effect of warning, ($F(1, 96) = 5.20$, $MSE = .006$). Additionally, the interaction of span and warning was not significant ($F < 1.00$) (Watson et al., 2005).

Results of experiment one also indicated that high spans recalled fewer critical words (.15) than low spans (.20), and warned participants recalled fewer critical words (.14) than non-warned participants (.21). A series of two spans (high or low) and two warnings (present or absent) *ANOVA* on false recall yielded a significant effect of span, (*F*(1, 96) = 4.00, *MSE*= .017), and a significant effect of warning, (*F*(1, 96) = 7.21, *MSE* = .017). The two-way interaction of span and warning in false recall of critical word was not significant (*F* < 1.00). Results of a separate planned *ANOVA* revealed that when both span groups were not warned to avoid false memories in the DRM paradigm, false recall was basically the same for high (.20) and low (.23) spans, (*F*(1, 48) = 0.38, *MSE* =.024, *p* = .54). However, when warned, high span recalled fewer non-presented critical words (.10) than low spans (.18), (*F*(1, 48) = 7.09, *MSE*= .011). Results of the experiments suggested that differences in the working memory capacity of young adults could influence false memories (Watson et al., 2005).

In experiment two, the presentation mode was switched from visual to auditory. Participants listened to the 60 word-list using headphones at an approximate rate of one word every 1.25 seconds. Participants were provided with materials to familiarize them with the testing procedures. In addition, the purpose of the assignment was explained to half of the high and low spans. A series of mixed *ANOVAs* were conducted on veridical recall, false recall of critical words, and other non-critical word intrusions (Watson et al., 2005). Close analysis of the results on veridical recall showed high spans recalling more studied words (.61) than low spans (.57). Additionally, a two (span) x two (warning) x five (study-test trial) *ANOVA* yielded a main effect of span, (*F* (1, 96) = 7.26, *MSE* = .036), and a main effect of study-test trial, (*F* (4, 384) = 1,483.74, *MSE* = .003). In regards to false recall of critical words, it was shown that fewer critical words (.26) were recalled by warned participants compared to non-warned participants (.36). A series of two (span) x two (warning) x five (study- test trial) *ANOVA* yielded a significant effect of warning, (F (1,96) = 6.27, MSE = .219), and a significant effect of study-test trial, (F (4,384) = 6.46, MSE = .029). Results of the study suggested that individual differences in the working memory capacity of young adults make them susceptible to false memory. However, the study also demonstrated that repeated study-test trial could serve to positively influence memory (Watson et al.).

Working Memory and Performance on National Curriculum

Working memory has also been linked to performance on national curriculum. Gathercole et al. (2004), examined the working memory and test scores of two groups of students: group one (n = 40) aged seven or eight and group two (n = 43) aged 14 or 15. Students' transcripts outlining their achievement level in English, mathematics, and science were evaluated. In addition, both groups completed a battery of working memory tests. Results of the study revealed that students who performed well in English and mathematics also scored well in working memory assessment. For the younger group, the study revealed a significant effect of English ability group on working memory scores, (F (10, 54) = 2.07, $p < 0.05$). In addition, there was also a significant effect of mathematics ability group on working memory, (F (10, 64) = 2.30, $p < 0.05$). For the older group, there was a significant effect of mathematics ability group on working memory, (F (8, 68) = 2.58, $p < 0.05$). There was also a significant effect of science ability group on working memory (F (8, 70) = 3.47, $p < 0.005$). However, at 14 years there was a weaker association between working memory and English scores (F (8, 62) = 1.64, $p >$ 0.05) (Gathercole et al.,). The weak link between working memory and English scores at age 14 suggests that working memory plays less of a role in English achievement at an older age.

The hypothesis that working memory impacts students' educational progress is supported by the results of a study conducted by Gathercole and Pickering (2000). Participants in this study were students (n = 83) aged 6 and 7 attending public school. The participants were assessed and divided into normal and low achievement groups based on the results of their performance on their national curriculum assessments in English and mathematics. These groups were comprised of students with no area of low achievement (n = 60) and students with one or more area of low achievement (n = 23). Low achievement students were comprised as follows: (a) low achievement in English only (n = 2), (b) mathematics only (n = 8), (c) English and mathematics (n = 13), and (d) English and or mathematics (n = 23). Participants also participated in a battery of 13 working memory assessments. All 13 working memory variables were normally distributed. In addition, skewness and kurtosis values were near zero with $p < .001$. The researchers found that children who performed poorly on their achievement tests also performed poorly on the working memory assessments. The most striking difference was observed in children with low achievements in English and or mathematics with central executive tasks. For example, significant achievement group effects (r = .81 to r = .89 with $p < .01$) were observed in the *MANOVA's* performed on the central executive tests.

Gathercole et al. (2003) examined the relationship between working memory and performance in national curriculum assessments in English, mathematics and science for two groups of students. The younger group (n = 40) consisted of 19 male and 21 female third grade students. The older group (n = 43) consisted of 18 male and 25 female tenth grade students. Students were categorized as low, average or high achiever based on their standardized test score. The students also completed a selection of working memory tests.

The researchers found high correlations ($r = 0.81$, $p < 0.001$) between the children's scores on working memory measures and mathematics and English achievement for the younger group. Very high correlations ($r = 0.90$, $p < 0.001$) was also found between the children's scores on working memory measures and mathematics and science achievement for the older group. These results suggest a link between working memory and students' achievement measured by performance on national assessment.

Working Memory and Emergent Literary Skills

The findings of Gathercole et al. (2004) support those of Bourke and Adams (2010) who suggested that there was a correlation between working memory and learning to read and write (emergent literary skill). Specifically, it was suggested that an individual's capacity to simultaneously process and store material could negatively impact emergent literary skills. Bourke and Adams examined the importance of a number of cognitive factors including working memory in accounting for the disparity in the development rate of students' emergent writing skills. Sixty seven students with mean age 57.30 months were assessed on working memory tasks. During the experiment, the students were asked to write their names and a story using a set of four pictures that they were given as a guide. After completing their story, they were asked to tell the experimenter what they wanted their story to convey. A writing assessment scale was used to assess the students' written text. Based on the results of this assessment, 27 of the children were classified as non-writers and 40 were classified as writers. Subsequent to this classification, cognitive assessments were conducted on the children on an individual basis in a quiet place in the school. The researchers performed a *MANOVA* to determine the interaction of working memory, language, reading, non-verbal cognitive skills and writing ability. The results of the analysis (Wilk's $\lambda = 0.59$, F (6, 60) = 6.80, $p < .01$) revealed significant differences among writers and non-writers on memory, language, reading and nonverbal cognitive skills. In addition, *ANOVAs* conducted on each dependent variable were significant. For example, the *ANOVA* for vocabulary, (F (1, 65) = 9.81, $p < .01$, $\eta^2 = 0.13$); word reading, (F (1, 65) = 40.14, $p < .01$, $\eta^2 = 0.38$); nonverbal ability, (F(1, 65) = 8.25, $p < .01$, $\eta^2 = 0.11$); complex listening span, (F(1, 65) = 7.18, $p < .01$, $\eta^2 = 0.10$); phonological loop, (F(1, 65) = 4.03, $p < .05$, $\eta^2 = .06$), and visual memory, (F(1, 65) = 6.79, $p < .01$, $\eta^2 = .09$) were all statistically significant (Bourke & Adams).

The Impact of Working Memory on Mathematics Achievement

Mathematics problem solving involves the simultaneous storing and processing of information. In addition, each individual must examine the specific problem presented and use their requisite knowledge to arrive at a solution (Kantowski, 1980; Schoenfeld, 1992). Consequently, researchers agree that mathematics problem solving could prove very challenging for individuals with limited working memory capacity as students need to employ a range of strategies in formulating mathematical solutions (Gathercole & Pickering, 2000; Gathercole et al., 2003; Gathercole et al., 2004; Hecht, 2002; LeBlanc & Weber-Russel, 1996; Passolunghi & Siegel, 2001; Passolunghi & Siegel, 2004; Swanson, Jerman & Zheng, 2008; Swanson & Sachse-Lee, 2001; Zheng et al., 2011).

Working Memory, Mathematics Ability and Cognitive Impairment

Passolunghi and Siegel (2004) examined the relationship among working memory, mathematics ability and cognitive impairment. A total of 49 fifth-grade students, 22 low achievers in mathematics and 27 normal achievers in mathematics participated in the study. A battery of tests including, mathematics, reading comprehension, vocabulary, and working memory tasks were conducted. Results of the study (t (47) = 6.1, $p < .0001$) suggested a general working memory deficit in children with mathematics difficulties (Passolunghi & Siegel). This finding is supported by the results of a study conducted by Bull, Espy and Wiebe (2008) who described the mathematics and reading achievement observed in a population of preschool and primary school students. Preschool students (n = 124) with mean age of 4.5 were tested in working memory skills. Standardized, norm-referenced school based assessment in phonics, reading and mathematics achievement was measured on entering the first year of primary school. These assessments were also conducted at the end of the first, third, fifth, and seventh year (Bull et al., 2008). Data was reported and examined for the first three time points. Analyses showed a significant correlation between working memory, mathematics, and reading skills at the beginning and end of primary school. These results are supported by a study conducted by Swanson et al. (2008), who examined the impact of cognitive growth in working memory on mathematics problem solving. A total of 353 students participated in this study. A battery of test assessing problem solving and working memory tasks were administered to the students. Swanson et al. reports that results supported the hypothesis that working memory growth predicts children's problem solving ability.

The Link Between Working Memory and Mathematics Achievement

Gathercole et al. (2004) examined the relationship between working memory and performance on mathematics, English and science on students aged seven and eight (n =

40) and students aged 14 and 15 ($n = 43$). The investigation had a dual purpose. In the first instance, Gathercole et al. (2004) sought to determine the persistence of earlier findings of close links between individual differences in working memory function and national assessment. The second purpose was to determine if this persistence extended to students aged 14 and 15. Each school provided transcripts of their pupils' standardized test scores which were all completed months earlier. In addition, both groups completed a battery of working memory tests. Results of the investigation for the younger group showed a significant effect (F (10, 64) = 2.07, $p < 0.05$) of working memory on English. There was also a significant relationship (F (10, 64) = 2.30, $p < 0.05$) of working memory on mathematics. Results of the investigation for the older group showed a significant effect of working memory on science (F (8, 70) = 3.47, $p < 0.005$). There was also a significant relationship of working memory on mathematics (F (8, 68) = 2.58, $p < 0.05$). However, the study showed no significant effect (F (8, 62) =1.64, $p > 0.05$) of English on working memory for the older group (Gathercole et al., 2004). In sum, the findings of Gathercole et al. (2003) and Gathercole et al. (2004) showed a strong link between primary and secondary school students' performance on national assessment and working memory. However, the results suggest a variance of the impact on working memory across curriculum. Specifically, some amount of inconsistency was observed between English ability and working memory for both groups of students. However, the link between mathematics achievement and working memory for both groups of students was significant.

Zheng et al. (2011) examined the connection between working memory components and word problem-solving accuracy in elementary school students. A total of

310 students (110 second graders, 82 third graders, and 118 fourth graders) participated in the study. Participants completed a battery of tests designed to assess working memory, problem-solving, reading, and mathematics calculation. The results ($x^2(29) = 52.42$, $p < .01$, ($x^2/df = 1.81$, *CFI* = .92, *TLI* = .91, *RMSEA* = .06 (.03, .09)) established among other things that working memory components impact word-problem solving accuracy.

Computerized Cognitive Training and its Impact on Working Memory

Working memory training is based on the theory of neuroplasticity which holds that an individual's brain can actually change as a result of systematic intensive training in a similar manner to how the muscles respond to exercise (Edlin et al., 2009; Klingberg et al., 2005; Sinha, 2005). Research suggests that computerized cognitive training programs have improved working memory and attention in stroke patients, children suffering from ADHD, healthy adults and older adults (Brigman & Cherry, 2002; Holmes et al., 2009; Klingberg et al., 2005; Westerberg & Klingberg, 2007).

Computerized Cognitive Training and Processing Speed

Working memory practice was shown to have an effect on processing speed and skill acquisition. Brigman and Cherry (2002) described the changes that occurred in a population of adults ($n = 40$) comprised of 20 students between the ages of 18 and 25 and 20 older adults between the ages of 60 and 75. Participants were trained for three consecutive days on an alphabet arithmetic task which required them to verify the accuracy of alphanumeric strings taking the form of letter–digit–letter. The display of the stimulus and the recording of response times and errors were computer controlled. The results of the study showed among other things a decrease in latency for both age groups. As shown, the main effect of session was significant (F (2, 76) = 63.83, MS_e = 76437539.11, $p < .001$). Subsequent sessions produced significantly faster reaction times.

Computerized Cognitive Training and ADHD

Results of a study conducted by Holmes et al. (2009) suggested that computerized cognitive training improved working memory in children suffering from ADHD. This is consistent with the findings of a study conducted by Klingberg et al. (2005). Holmes et al. compared the impact of stimulant medication and a computerized cognitive training program on the working memory of children suffering from ADHD. Children (n = 25) aged 8 to 11 years were required to complete 20 to 25 daily sessions involving a series of working memory tasks. The program also included a motivational and reward component. In addition, other assessments of working memory and IQ were completed before and after training, and with and without prescribed medication (Holmes et al.,) In general, it was shown that training led to greater gains than medication alone for all aspect of working memory except visuospatial working memory. In addition, it was reported that training gains persisted over a six-month period. Holmes et al., reported that computerized cognitive training led to significant gains in the following four components of working memory: verbal short term memory (F(1, 24) = 8.64, MSE = 162.58, p = .01), visuospatial short term memory (F (1, 24) = 47.00, MSE = 130.13, p <.01), verbal working memory (F (1, 24) = 9.66, MSE = 113.88, p = .01), and visuospatial working memory (F (1, 24) = 4.27, MSE = 170.82, p =.05).

Klingberg et al. (2005) investigated the effect of improving working memory by computerized practice. Children (n = 53) aged 7 to 12 years suffering from ADHD were randomly assigned to use either a treatment computer program designed to boost working memory or a comparison program designed to have minimal or no effect on working memory. Fifty participants successfully completed the program. Of this number, 44 met the criterion for sufficient compliance, defined as 20 or more days of program use. Of the 44 who met the criterion for sufficient compliance, 42 students were evaluated at follow-up 3 months later (Klingberg et al.,). Klingberg et al. (2005) compared two similar versions of the same training program in this study. Both versions included visuo spatial and verbal working memory tasks. Participants performed 90 working memory trials on each day of training and responded by clicking on displays with the computer mouse. The difficulty level of the activities pursued by students in the treatment program was continuously adjusted to match the child's working memory capacity. The same tasks were used in the control group. However, the difficulty level of the program was not adjusted to match the child's working memory capacity (Klingberg et al., 2005). The results (n = 44, r^2 = .49, β =.79, p = .001) of the statistical analysis showed a significant improvement for the main outcome measure from baseline to post-intervention in the treatment group compared with the comparison group. Parents of the children with memory training reported a reduction in their children's hyperactivity (n = 37, r^2 = 73, β = -3.4, p = .03) and inattention (n = 37, r^2 = .50, β = -3.5, p = .04) three months after the intervention. These results suggest that the working memory of children suffering from ADHD can be improved by computerized cognitive training (Klingberg et al., 2005).

Computerized Cognitive Training and Healthy Adults

It appears that computerized cognitive training can enhance brain activity in healthy adults. Westerberg and Klingberg (2007) analyzed the effect of computerized training on brain activity of an experimental group of healthy adults (*n* = 3). On day one, each participant was tested on four cognitive tasks, and then undertook an initial scanning session. Participants participated in a second scanning session on day two. Participants were allowed to participate in working memory training following the completion of the cognitive tests and scanning sessions. Working memory training involved participants practicing four to six days a week for five weeks on three working memory tasks (visuospatial, span board and stroop). A third scanning session along with completion of cognitive tasks was completed five weeks after scanning session two. Brain activity was measured with functional magnetic resonance imaging (fMRI) during performance of a working memory and a baseline task. In addition to the experimental group, a control group of healthy adults (*n* = 11) undertook testing with a five week test-retest period for comparative analysis using the Wilcoxon Signed-rank test. Comparison of the results of the test-retest between the experimental and control group suggested that training significantly improved performance on working memory tasks as follows: visuospatial working memory task ($p < 0.001$), Span-board ($p < 0.001$), RPM ($p < 0.01$) and stroop task ($p < 0.05$). Post training testing was conducted eight months later on two subjects. The results compared to pre-training was significantly larger with ($p < 0.01$) for both subjects (Westerberg & Klingberg). Westerberg & Klingberg explained that two factors time (before vs. after training) and task (baseline vs. working memory) were used to analyze fMRI data. This analysis showed significant positive interaction between time and task in the right inferior (X = 42, Y = -57, Z = 45) and middle frontal gyrus (X = 36, Y = 21, Z = 18), and in the intra parietal cortex (X = 18, Y = -69, Z = 48), and inferior parietal cortex (X = 42, Y = 57, Z = 45). However, "negative time-by-task interaction (lower task-related activity after training) was only found in the anterior cingulate motor area (pre-SMA) (X = −3, Y = 6, Z = 45)" (p. 190).

Computerized Cognitive Training and Stroke Patients

Westerberg et al. (2007) established that computerized working memory training improved working memory and attention in stroke patients. In this study, data from participants ($n = 18$) who were randomized to either a treatment or control group were captured. Participants practiced on working memory task for five weeks. There was significant improvement in the treatment group on the neuropsychological tests span board ($p < 0.05$), PASAT ($p < .001$) and Ruff 2 & 7 ($p < 0.005$) and self-rating questionnaire ($p < 0.005$).

Summary

Cognitive information processing is concerned with looking at the operations of memory. To date, there are a number of information processing models. However, the multi-store model first described by Atkinson and Shiffrin (1968) is one of the most widely accepted cognitive information processing models (Driscoll, 2005; Schunk, 2008). In their model, Atkinson and Shiffrin portrayed memory as having three stages in the following order: sensory, short-term and long-term. Atkinson and Shiffrin hypothesized that information that made it through sensory memory are transferred to a unitary short-term memory for further processing. They theorized that information held in short-term memory are either strengthened by rehearsal or lost. They put forward that items strengthened by rehearsal are subsequently sent to long-term memory for permanent storage.

Baddeley and Hitch's (1974) multiple-component working memory model was proposed as an alternative to Atkinson and Shiffrin's (1968) unitary short-term memory. The multiple-component working memory model is presented as consisting of a central executive, a phonological loop and a visuospatial sketchpad. Baddeley (2000) introduced an episodic buffer as a further subcomponent of working memory. As discussed, working memory has been associated with; the development of emergent writing skills, information recall, false memories, poor performance on national assessments and low achievement (Bourke & Adams, 2010; Gathercole & Pickering, 2000; Gathercole et al., 2004; Watson et al., 2005).

Low achievers can be described as poor academic performers who typically achieve less than the average student (Hargis, 2006; Gresham et al., 1996). As discussed, there are a number of factors including working memory which impact students and influence achievement (Balfanz & Byrnes, 2006; Gottfried, 2010; Madyun & Lee, 2010; Stotsky, 2010). However, studies have suggested that working memory is malleable and can be enhanced by training (Brigman & Cherry, 2002; Edlin et al., 2009; Gunther et al., 2003; Holmes et al., 2009; Klingberg et al., 2005). This suggestion has influenced the development of computerized training programs purporting to help users with deficiencies in working memory. Considering the possibility that an increase in working memory can improve children's cognitive capacity and possibly contribute to improved academic performance, this study was designed to examine if low achievers could benefit from use of these programs.

Chapter 3

Methodology

Introduction

Chapter 3 provides a detailed step-by-step description of the pre-test post-test control group experimental design utilized in this study. First, a restatement of the research questions and hypotheses are presented. This is followed by a discussion of the independent, dependent and intervening variables. Next, a detailed description of the instruments, participant selection and assignment process is provided. The testing methods, analysis, ethical considerations, and resources are then examined.

Research Questions

The following research questions were addressed in this study:

1. What impact did computerized cognitive training have on the working memory capacity of fifth grade low achievers?
2. If working memory capacity significantly improved, to what extent will this improvement affect the mathematics achievement of fifth grade primary school low achievers?

Hypotheses

A random pre-test-post-test control-group experimental study was conducted to test the following research hypotheses:

1. There will be no significant difference in working memory capacity (as measured by the *Automated Working Memory Assessment* (Alloway, 2007) between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.
2. There will be no significant difference in mathematics achievement (as measured by the Grade Four Literacy Test) immediately after training between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.
3. There will be no significant difference in mathematics achievement six weeks after training between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.

A number of researchers have shown a correlation between computerized cognitive training and improvements in working memory. For example, Klingberg et al. (2005) demonstrated that working memory can be improved in children with ADHD. Gunther et al. (2003) showed that computerized cognitive training had a positive effect on age related working memory problems. To this end, hypothesis one is an extension of these researches. However, the main difference between the proposed research and previous studies is that this study confined the research to a specialized population of low achievers.

The findings of Gathercole and Pickering (2000) influenced the decision to formulate hypothesis two. In their study, the researchers found close association between students' academic performance at age seven and their working memory capacity. Analysis of students' (*n* = 83) working memory test battery and performance on national curriculum showed a close association between working memory and academic achievement. Therefore, hypothesis two served to test the findings of Gathercole and Pickering in a group of fifth grade students. Hypothesis three is also influenced by the work of Gathercole and Pickering (2000) described above. However, instead of testing to see if there is improvement in academic achievement, this hypothesis was designed to determine persistence.

Variables

Independent Variable

Experimental research seeks to examine the cause and effect between the independent and dependent variable (Gay et al., 2006). The independent variable in experimental research is conceptualized as the factor that is manipulated by the researcher (Gay et al.,). Table 1 shows the research questions, the type of variable and control of intervening variables. In this study, the type of training received is the independent variable. The experimental group of students received progressive computerized cognitive training. The control group received basic computerized working memory training.

Group 1 - Low achieving students that received progressive computerized cognitive training.

Group 2 - Low achieving students that received basic computerized cognitive training.

Dependent Variables

Gay et al. (2006) describe the dependent variable in experimental research as “the variable hypothesized to depend on or be caused by the independent variable” (p. 125). In this study, measures of working memory achievement and mathematics achievement were used as the dependent variables. The *Automated Working Memory Assessment* (Alloway, 2007) and the Grade Four Literacy Tests are used as the outcome measures for this study.

Outcome measure 1 - The *Automated Working Memory Assessment* (Alloway)

Outcome measure 2 - Grade Four Literacy Test.

Intervening Variables

Extraneous and intervening variables such as SES, academic and personal factors can confound this study. Therefore, a combination of random assignment and a pre-test post-test control group design were used to control sources of internal and external threats to validity (Gay et al., 2006). In addition, valid and reliable instruments were used to measure academic achievement and changes in working memory capacity for both the control and experimental group. Two similar versions of the same program were compared in this study. Students in the treatment program were presented with tasks whose difficulty increased to match their working memory capacity. Students in the control group completed the same tasks. However the difficulty level of the program was not increased to match the students’ working memory capacity. Using two similar versions of the same program controlled for nonspecific effects of the training program (Klingberg et al., 2004).

Instruments

Instruments used for research should be both reliable and valid. Reliability refers to the degree to which a test consistently measures what it is measuring (Gay et al., 2006). To this end, “scores from a reliable instrument are stable and consistent” (Creswell, p. 169). Validity on the other hand refers to the appropriateness of the testing instrument (Gay et al.,). Therefore, individual scores from a valid instrument make sense, are meaningful, and enable the researcher to draw valid conclusions from the study sample (Creswell, 2008).

Grade Four Literacy Test

The Grade Four Literacy *Test* is a paper-and-pencil based standardized test. It is divided into two sections, section one consists of 46 multiple choices items and should be completed in 60 minutes, section two consists of three word problems and should be completed in 20 minutes. Government educational consultant, author and principal of Rollington Town Primary School in Jamaica M. Bailey stated that the Grade Four Literacy Test is a valid and reliable instrument (personal communication, January 21, 2013).

Automated Working Memory Assessment

Alloway, Gathercole, Kirkwood and Elliott (2008) investigated the construct stability and diagnostic validity of the *Automated Working Memory Assessment*. The first objective of their study was to investigate the construct stability of the *Automated*

Working Memory Assessment (Alloway, 2007) in children with low working memory. The researchers compared the memory scores of children with working memory deficits at the beginning and end of a full school year to investigate whether these skills would differ either as a function of development or of learning. The second objective of the study was to evaluate the efficacy of using the *Automated Working Memory Assessment* (Alloway, 2007) as a tool to detect children who were susceptible to problems learning. Children with low and average working memory capacity were identified on the basis of their scores on two verbal working memory tests: backward digit recall and listening recall. The researchers examined the diagnostic validity of the *Automated Working Memory Assessment* (Alloway) by comparing performance on these tests with the Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) Working Memory Index. The findings indicated no changes over the school year in the working memory skills of the students diagnosed with working memory challenges. In addition, moderate associations were found for non-word recall, dot matrix, and spatial recall (r = .51, r = .50, and r = .44, respectively). Performance between the *Automated Working Memory Assessment* (Alloway) and the *WISC-IV Working Memory Index* was similar (F = 28.38, p < .001) (Alloway et al., 2008).

The ability to improve the working memory capacity of low achievers (research question 1) was measured by the *Automated Working Memory Assessment* (Alloway, 2007). The ability to use the skills from progressive computerized cognitive training to improve mathematics achievement (research question 2) was measured using the Grade Four Literacy Test. Changes in the Grade Four Literacy Test scores and the *Automated Working Memory Assessment* (Alloway) scores over three testing sessions (pre-training, immediately post training and at six weeks post training) were used to determine the acceptance or rejection of the hypotheses.

Study Sample

As the research problem narrows, it is imperative to specifically and clearly decide who constitutes the study population (Kumar, 2011). This is important as the adequacy of the sample size affects the external validity and generalizability of the study (Gay et al., 2006). Creswell (2008) recommends a sample size of 15 participants per group for an experimental study. A total of 30 fifth-grade students were selected from a population of low achieving primary school students (Figure 2). These students were classified as low achievers and placed in the same class on the basis of their below average performance on the standardized national Grade Four Literacy Test.

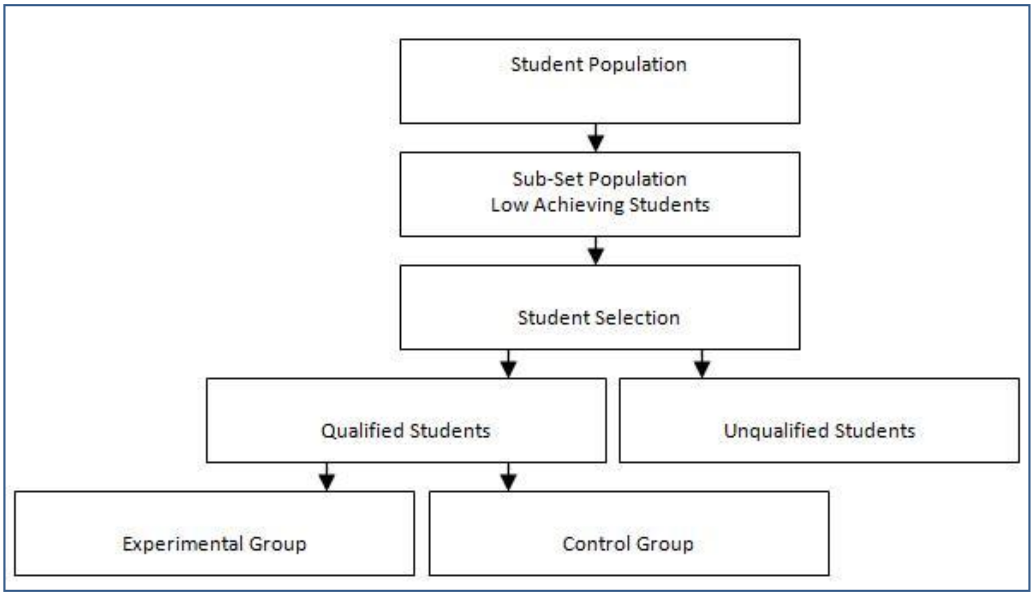

Figure 2. Student selection

Students were selected if they met the following criteria:

1. They were primary school fifth grade students who performed below average on the standardized national Grade Four Literacy Test.
2. They stated their commitment to participate in the pre-test, post-test and computerized training sessions.
3. Their parents consented to their participation in the study.
4. They had no diagnosed learning disability.
5. They had not participated in previous computerized cognitive training programs.
6. They were not taking cognitive enhancement drugs.

The study was approved by the Institutional Review Board (IRB) of Nova Southeastern University and by the principal at the participating school. Written consent forms were obtained from all parents and students.

Pre-Test Protocol

The pre-testing of participants' working memory capacity was supervised by an experienced psychologist using the *Automated Working Memory Assessment* (Alloway, 2007). The students were tested individually in a quiet place at their school in two sessions within a single week (Gathercole et al., 2004). Participants were tested on four subtests of the *Automated Working Memory Assessment* (Alloway) namely: (a) verbal short term memory (digital recall), (b) verbal working memory (listening recall), (c) visuospatial short term memory (dot matrix), and (d) visuospatial working memory (spatial recall). In addition to working memory assessment, participants were pre-tested by their grade teacher in mathematics achievement using the Grade Four Literacy Test. Therefore, information pertaining to working memory performance as well as mathematics scores before training was collected.

Experimental Protocol

Students were randomly assigned to either the experimental or control group. Training was conducted the same time each day by the class teacher at the participants' school. The experimental group of students received progressive computerized cognitive training. The duration for practice on the computerized training program was one hour per day for five weeks. This five weeks duration was supported by the findings of a large-scale randomized study conducted by Willis et al. (2006). In this study, participants (n = 2,802), showed significant working memory and cognitive improvement after receiving cognitive training for two hours per week for five weeks.

The progressive computerized working memory training program consisted of a set of adaptive working memory span tasks (exercises). These exercises included numerous sequences of to-be-remembered items (trials) that the students had to hold in mind and repeat either forward or backwards after a short delay. The program was provided via the Internet and used by the students on a personal computer in the school's computer lab. Students were required to remember visuospatial tasks (recalling the position of objects) and verbal tasks (recalling letters or digits). Responses were made by clicking objects on the computer monitor with the mouse. A session (day) constituted eight practice exercises, with each exercise consisting of 15 trials for a total of 120 trials. The difficulty level of the program was automatically adjusted on a trail by trial basis to match the working memory capacity of the student. Students' progress was logged on Cogmed's server. A racing program which served as a motivational aid was included in the training program. Participants were able to play this game after successfully completing each day's work. Features of the program included a display of the participant's best score as well as a display of the accumulation of energy based on performance. This racing feature was included as a reward and did not influence working memory capacity.

Control Protocol

The control group received basic computerized working memory training. Basic computerized working memory training differed from progressive computerized working memory training in that the difficulty level of the program was not increased to match the working memory capacity of the students (Klingberg et al., 2005). The basic computerized working memory training consisted of non-adaptive working memory exercises. These exercises included few sequences of to-be-remembered items (trials) that the students had to hold in mind and repeat either forward or backwards after a short delay. The program was provided via the Internet and used by the students on a personal computer in the school's computer lab. Students were required to remember visuospatial tasks (recalling the position of objects) and verbal tasks (recalling letters or digits etc.). Responses were made by clicking the computer monitor with the mouse. A session constituted eight practice exercises, with each exercise consisting of two to three trials. Training was conducted the same time each day by the class teacher at the participants' school. The duration for practice on the basic computerized training program was one hour per day for five weeks.

Post-Test Protocol

After the five weeks of training, all participants were tested in working memory using the *Automated Working Memory Assessment*. Additionally, participants were post-tested in mathematics achievement using the Grade Four Literacy Test. The end of term (approximately six weeks following the computerized cognitive training) mathematics scores for all participants were analyzed to determine if there were statistically significant differences in mathematics achievement between the experimental and control group.

Analysis

The working memory of the group receiving progressive computerized working memory training was compared to the group receiving basic computerized working memory training immediately after training using a repeated measures *MANOVA*. The mathematics achievement of the group receiving progressive computerized working memory training was compared to the group receiving basic computerized working memory training immediately after training and six weeks post training using a repeated measures *MANOVA*.

A *MANOVA* is a statistical tool used for comparing multivariate means of several groups constituting two or more dependent variables. A *MANOVA* investigates whether there is significance among independent variables. Specifically the *MANOVA* seeks to determine whether independent variables on their own or in conjunction with one another have a significant effect on the dependent variables. The *MANOVA* examines the degree of variance within the independent variables and determine if it is smaller than the degree of variance between the independent variables. If the within subject variance is smaller than the between subjects' variance then this suggests that the independent variables had a significant effect on the dependent variables. A *MANOVA* uses a number of multivariate measures (such as Wilks' lambda, Pillai's trace, Hotelling trace and Roy's largest root) to determine significance. *MANOVAs* should be used for group comparison where there is one or more independent variables and two or more dependent variables. *MANOVAs* should be used when there are zero covariates, consisting of categorical independent variables, continuous dependent variable with normal distribution scores (Creswell, 2008). Dependent variables in *MANOVAs* should conform to the following assumptions:

1. There should be more participants than dependent variables. The sample size should be adequate. A greater amount of variance is attributed to error in smaller sample sizes and this could negatively impact findings. A Box's M test (Figure 3) was performed

to determine adequacy of the study’s sample size. As shown, the significant value is greater than 0.05, this suggests that the sample size assumption was satisfied.

Box's M	5.126
F	.746
df1	6
df2	4603.013
Sig.	.613

Figure 3. Box's M Test of Equality of Covariance Matrices

2. Highly correlated dependent variables should not be placed in the same model.
3. There should be homogeneity of variance covariance. This supports the assumption that the subjects are drawn from a similar population.

The mentioned assumptions were satisfied in this study.

Ethical Considerations

Parents of the students who met the criteria for inclusion were required to complete the informed consent form (Appendix A). Coded IDs were created and used for data collection and analysis. The list linking the IDs is kept in a fireproof cabinet at the researcher’s home. This list will be destroyed three years after the close of the study. Furthermore, online data was stored on a secured server and is password protected.

Resources

The study was conducted at a primary school in Kingston, Jamaica with low achieving fifth grade students. The Cogmed Working Memory Training software and the *Automated Working Memory Assessment* (Alloway, 2007) program were provided by Pearson Education. The SPSS statistical software was used to evaluate the pre-test and post-test data. The Grade Four Literacy Test was obtained from the Ministry of Education Jamaica. The primary investigator along with the class teacher supervised all the practice sessions. An experienced psychologist supervised all pre-testing and post-testing procedures.

Summary

A pre-test post-test control group experimental design was utilized to compare the effectiveness of a computerized cognitive training program in a specialized population of low achieving students. A sample of low achievers was randomly selected from a primary school located in a low SES community in Kingston Jamaica. All participants were pre-tested in working memory using the *Automated Working Memory Assessment* (Alloway, 2007). Additionally, participants were pre-tested in mathematics achievement using the Grade Four Literacy Test. Participants were randomly assigned to either the experimental or control group. The experimental group of students received progressive computerized cognitive training. The control group received basic computerized working memory training, in which the difficulty level of the program was not be increased to match the working memory capacity of the students (Klingberg et al. 2005).

Training was conducted at the participants' school. The duration for practice on the computerized training program was five weeks. After the five weeks of training, all participants were tested in working memory using the *Automated Working Memory Assessment* (Alloway, 2007). Participants were also tested in mathematics using the Grade Four Literacy Test immediately post training and six weeks post training. The working memory of the group receiving progressive computerized working memory training was compared to the group receiving basic computerized working memory training using a Repeated Measures *MANOVA*. The mathematics achievement of the group receiving progressive computerized working memory training was compared to the group receiving basic computerized working memory training using a Repeated Measures *MANOVA*. Statistically significant changes appearing in the experimental group from pre-test to post-test and not in the control group were attributed to the effect of the computerized cognitive training program.

Chapter 4

Results

Introduction

Of the 30 students who participated in the study, two withdrew because of social problems unrelated to the study. Therefore, a total of 28 students completed pre-testing, post-testing and the training sessions. Students participated in either progressive computerized working memory training or basic computerized working memory training. All participants were pre-tested in four areas of working memory: (a) verbal short term memory, (b) verbal working memory, (c) visuospatial short term memory, and (d) visuospatial working memory using the *Automated Working Memory Assessment* (Alloway, 2007). Students were also tested in mathematics achievement using the Grade Four Literacy Test prior to beginning the five week training sessions. Students were tested in working memory and mathematics achievement immediately post training. In addition, the end of term mathematics results of all participants were collected. The working memory of the group receiving progressive computerized working memory training was compared to the group receiving basic computerized working memory training immediately after training using a Repeated Measures *MANOVA*. The mathematics achievement of the group receiving progressive computerized working memory training was compared to the group receiving basic computerized working memory training using a Repeated Measures *MANOVA*.

Findings

Hypothesis 1

> There will be no significant difference in working memory capacity (as measured by the *Automated Working Memory Assessment* (Alloway, 2007) between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.

Both experimental and control groups subjects showed improvements in working memory scores from the baseline pre-test to the post-test (Figure 4). Analysis of the multivariate tests (Figure 5) suggests that there was significant difference (Wilks Lambda (F = 2.880, p = .045)) between the group receiving progressive computerized working memory training compared to the group receiving basic computerized working memory training. The null hypothesis was rejected.

Descriptive Statistics

	Treatmenttime	Mean	Std. Deviation	N
Pre Test - Verbal Short Term Memory	Control	88.0769	15.07460	13
	Experimental	89.6667	15.29083	15
	Total	88.9286	14.92929	28
Pre Test - Verbal Working Memory	Control	81.1538	16.22162	13
	Experimental	76.6667	12.63027	15
	Total	78.7500	14.31297	28
Pre Test - Visuospatial Short Term Memory	Control	81.1538	12.77267	13
	Experimental	81.3333	12.16944	15
	Total	81.2500	12.21907	28
Pre Test - Visuospatial Working Memory	Control	79.6154	15.74028	13
	Experimental	75.3333	12.16944	15
	Total	77.3214	13.84318	28
Post Test - Verbal Short Term Memory	Control	91.5385	14.48916	13
	Experimental	99.3333	10.83425	15
	Total	95.7143	13.03232	28
Post Test - Verbal Working Memory	Control	88.4615	14.34466	13
	Experimental	101.3333	14.93637	15
	Total	95.3571	15.80720	28
Post Test - Visuospatial Short Term Memory	Control	90.7692	7.86505	13
	Experimental	103.0000	7.27029	15
	Total	97.3214	9.66879	28
Post Test - Visuospatial Working Memory	Control	86.5385	14.48916	13
	Experimental	87.6667	13.87015	15
	Total	87.1429	13.90634	28

Figure 4. Working Memory Descriptive Statistics

Multivariate Tests[a]

Effect			Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[c]
Between Subjects	Intercept	Pillai's Trace	.994	895.671[b]	4.000	23.000	.000	.994	3582.683	1.000
		Wilks' Lambda	.006	895.671[b]	4.000	23.000	.000	.994	3582.683	1.000
		Hotelling's Trace	155.769	895.671[b]	4.000	23.000	.000	.994	3582.683	1.000
		Roy's Largest Root	155.769	895.671[b]	4.000	23.000	.000	.994	3582.683	1.000
	Group	Pillai's Trace	.309	2.571[b]	4.000	23.000	.065	.309	10.286	.629
		Wilks' Lambda	.691	2.571[b]	4.000	23.000	.065	.309	10.286	.629
		Hotelling's Trace	.447	2.571[b]	4.000	23.000	.065	.309	10.286	.629
		Roy's Largest Root	.447	2.571[b]	4.000	23.000	.065	.309	10.286	.629
Within Subjects	Treatmenttime	Pillai's Trace	.578	7.866[b]	4.000	23.000	.000	.578	31.464	.991
		Wilks' Lambda	.422	7.866[b]	4.000	23.000	.000	.578	31.464	.991
		Hotelling's Trace	1.368	7.866[b]	4.000	23.000	.000	.578	31.464	.991
		Roy's Largest Root	1.368	7.866[b]	4.000	23.000	.000	.578	31.464	.991
	Treatmenttime * Group	Pillai's Trace	.334	2.880[b]	4.000	23.000	.045	.334	11.521	.686
		Wilks' Lambda	.666	2.880[b]	4.000	23.000	.045	.334	11.521	.686
		Hotelling's Trace	.501	2.880[b]	4.000	23.000	.045	.334	11.521	.686
		Roy's Largest Root	.501	2.880[b]	4.000	23.000	.045	.334	11.521	.686

a. Design: Intercept + Group
Within Subjects Design: Treatmenttime

b. Exact statistic

c. Computed using alpha = .05

Figure 5. Working Memory Multivariate Tests

Hypothesis 2

There will be no significant difference in mathematics achievement (as measured by the Grade Four Literacy Test) immediately after training between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.

The experimental group demonstrated a greater improvement in mathematics achievement than the control group immediately post training (Figure 6). However, this improvement was not statistically significant (F = 2.719, p = .085) (Figure 7). The null hypothesis in this case was not rejected.

Hypothesis 3

There will be no significant difference in mathematics achievement six weeks after training between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.

The experimental group demonstrated a greater improvement in mathematics scores than the control group six weeks post training (Figure 6). However, this improvement was not significant (F = 2.719, p = .085) (Figure 7). The null hypothesis in this instance was not rejected.

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Mathematics Pre Test	Control	29.6923	10.38737	13
	Experimental	31.0000	12.84523	15
	Total	30.3929	11.57372	28
Mathematics Post Test	Control	34.0000	12.05543	13
	Experimental	41.8000	13.03950	15
	Total	38.1786	12.97877	28
Mathematics Six Weeks	Control	53.6923	15.85552	13
	Experimental	61.2000	19.75276	15
	Total	57.7143	18.12683	28

Figure 6. Mathematics Descriptive Statistics

Multivariate Tests[a]

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Treatmenttime	Pillai's Trace	.703	29.578[b]	2.000	25.000	.000	.703
	Wilks' Lambda	.297	29.578[b]	2.000	25.000	.000	.703
	Hotelling's Trace	2.366	29.578[b]	2.000	25.000	.000	.703
	Roy's Largest Root	2.366	29.578[b]	2.000	25.000	.000	.703
Treatmenttime * Group	Pillai's Trace	.179	2.719[b]	2.000	25.000	.085	.179
	Wilks' Lambda	.821	2.719[b]	2.000	25.000	.085	.179
	Hotelling's Trace	.217	2.719[b]	2.000	25.000	.085	.179
	Roy's Largest Root	.217	2.719[b]	2.000	25.000	.085	.179

a. Design: Intercept + Group
Within Subjects Design: Treatmenttime

b. Exact statistic

Figure 7. Mathematics Multivariate Tests

Summary

A total of twenty eight students completed the study. Students participated in either progressive computerized working memory training or basic computerized working memory training. Students were tested in mathematics achievement using the Grade Four Literacy Test prior to beginning the five weeks training sessions. Participants were also tested in working memory and mathematics achievement immediately post training. In addition, the end of term mathematics results of all participants were collected.

Both experimental and control groups subjects showed improvements in working memory scores from the baseline pre-test to the post-test (Figure 4). Analysis of the multivariate tests (Figure 5) suggests that there was significant difference (Wilks Lambda (F = 2.880, p = .045)) between the group receiving progressive computerized working memory training compared to the group receiving basic computerized working memory training. The null hypothesis was rejected.

The experimental group demonstrated a greater improvement in mathematics achievement than the control group immediately post training (Figure 6.). However, this improvement was not statistically significant ($F = 2.719$, $p = .085$) (Figure 7). The experimental group demonstrated a greater improvement in mathematics scores than the control group six weeks post training (Figure 6.). However, this improvement was not significant ($F = 2.719$, $p = .085$) (Figure 7.). The null hypothesis was not rejected.

Chapter 5

Conclusions

Introduction

The goal of this study was to determine whether low achieving fifth grade primary school students would significantly improve their working memory capacity (as measured by the *Automated Working Memory Assessment* (Alloway, 2007)) and mathematics achievement (as measured by the Grade Four Literacy Test) through computerized cognitive training on working memory. Results of studies conducted by Brigman and Cherry (2002), Holmes et al. (2009), Klingberg et al. (2005), and Westerberg and Klingberg (2007) demonstrated that computerized cognitive training programs have improved working memory capacity and attention in stroke patients, regular middle school students, children suffering from ADHD, healthy adults, and older adults. However, the impact of computerized cognitive training on the working memory of low achieving primary school students was not adequately examined. Hence, this study examined the interactions among working memory, computerized cognitive training and academic achievement.

A pre-test post-test control-group experimental study was conducted to test the research hypotheses. A total of 30 fifth-grade students were selected from a population of low achieving primary school students. These students were classified as low achievers and placed in the same class on the basis of their below average performance on the standardized national Grade Four Literacy Test. The students were randomly assigned to either the experimental or control group. Students practiced for one hour per day for five weeks. This study demonstrated that low achieving fifth grade primary school students who practiced on a progressive computerized cognitive training program can improve their memory.

Discussion

The following two questions motivated the study.

1. What impact will computerized cognitive training have on the working memory capacity of fifth grade primary school low achievers?
2. If working memory capacity significantly improved, to what extent will this improvement affect the mathematics achievement of fifth grade primary school low achievers?

Hypothesis one was tested to answer research question one. Hypotheses two and three were tested to answer research question two.

Hypothesis 1

There will be no significant difference in working memory capacity (as measured by the *Automated Working Memory Assessment* (Alloway, 2007) between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.

All participants were tested in four areas of working memory: (a) verbal short term memory, (b) verbal working memory, (c) visuospatial short term memory, and (d) visuospatial working memory using the *Automated Working Memory Assessment* (Alloway, 2007). The experimental subjects demonstrated a statistically significant greater improvement in working memory scores from the baseline pre-test to the post-test than did the control group. The null hypothesis was rejected.

The greater improvement in working memory scores in the experimental group addressed research question one and provided support for the use of computerized cognitive training programs as an effective tool to enhance the working memory capacity of 5th grade primary school low achievers.

Results of research conducted by Brigman and Cherry (2002); Gathercole et al. (2004); Holmes et al. (2009) and Klingberg et al. (2005), support the hypothesis that computerized working memory training improves working memory capacity. For example, Klingberg et al. (2004) conducted a study to determine whether systematic training of working memory over a five weeks period would improve working memory and other executive functions and reduce ADHD symptoms. In their multicenter, double-blinded, controlled study, subjects (n = 53) were randomly assigned to use either the treatment computer program for training working memory or a comparison program. Results of the study demonstrated a significant treatment effect in working memory capacity post intervention and at follow up.

Hypotheses two and three were tested to answer research question two which asked: If working memory capacity significantly improved, to what extent will this improvement affect the mathematics achievement of fifth grade primary school low achievers?

Hypothesis 2

There will be no significant difference in mathematics achievement (as measured by the Grade Four Literacy Test) immediately after training between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.

The experimental group demonstrated a greater improvement in mathematics achievement than the control group immediately post training (Figure 6). However, this improvement was not statistically significant (*F* = 2.719, *p* =.085) (Figure 7). The null hypothesis in this case was not rejected.

Hypothesis 3

There will be no significant difference in mathematics achievement six weeks after training between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.

The experimental group demonstrated a greater improvement in mathematics scores than the control group six weeks post training (Figure 6). However, this improvement was not significant (*F* = 2.719, *p* = .085) (Figure 7). The null hypothesis in this instance was not rejected.

The findings of hypotheses two and three join a chorus of mixed results regarding transfer gains from computerized cognitive training. The findings are consistent with the those of Harrison, Shipstead, Hicks, Hambrick and Redick (2013); Melby-Lervåg and Hulme (2013) and Rode, Robson, Purviance, Geary and Mayr (2014) who all reported disappointing generalized effects from intense working memory training. In their study, Rode et al. conducted research to determine the effectiveness of computerized working memory training on improving working memory tasks, academic achievement, and classroom behavior. In their multicenter study, third grade students (*n* = 282) were randomly assigned to use either an adaptive computerized working memory training program or regular classroom activities. The computerized working memory training program consisted of storage (series of numbers to memorize) and process (mathematics calculations) exercises. Results of their study (*WIAT Math t* =.39, *d*=.05, *WIAT Reading t* = 1.39, *d* =.17, *CMB Math t* = 2.20, *d* = .26, *CBM Reading t* = 1.27, *d* = .15, Teacher Rating *t* = 3.15, *d* = .37, *AWMA t* = 2.01, *d* =.24) showed a small and insignificant effect size of training-specific transfer gain across tasks.

On the contrary, result of studies conducted by Chein and Morrison (2010); Jaeggi et al. (2008) and Klingberg et al. (2005) demonstrated significant transfer effects of working memory training. In their study, Chein and Morrison (2010) tested the malleability of working memory capacity and the extent to which the benefits of working memory training could be transferred to other cognitive skills. College students (n = 42) completed four weeks of working memory training. Working memory results ($t = 7.06$, $p < .005$) in trained participants suggests that working memory training improves measures of temporary memory. Furthermore, working memory training promoted significant increases ($t = 2.36$, $p = .015$) in reading and comprehension in the trained participants.

Limitations

Creswell (2008) describes limitations as “potential problems with the study identified by the researcher” (p.207). A number of factors could have limited the finding of this study. This study was focused on examining fifth grade low achievers. To accomplish this feat, all 30 students in the sole low achieving fifth grade class at a primary school in Kingston Jamaica were included in the study. Creswell (2008) endorses the inclusion of approximately 15 participants in each group in an experiment. However, despite this endorsement, this modest number of participants could potentially limit the result findings as statistical tests favor a large sample size in order to decrease sampling error and ensure generalizability.

Experimental mortality was also a limiting factor. Of the 30 students who participated in the study, two withdrew because of social problems unrelated to the study. This attrition altered the composition of the control group. This alteration could have potential negative impact on the significance of the research results.

Students participating in the current study were all from a low socioeconomic background. This presented numerous challenges. As discussed, the influence of socioeconomic status on academic achievement is irrefutable. Socioeconomic status impacts (a) readiness for school, (b) students' engagement in learning activities, (c) attention, (d) social skills, (e) literacy, (f) later school performance, (g) learning-related behavior problems, and (h) school attendance (Coley, 2002; Madyun & Lee, 2010; Morgan, Farkas, Hillemeier & Maczuga, 2008; Pianta & Stuhlman, 2004; Schunk, 2008). Participating students displayed poor social skills and kept the researcher and the supervising teacher on their toes in order to keep them focused.

Some students missed training days for numerous reasons (see Table 2). However, the number of days missed was not significantly different ($p = 0.3711$) between the groups. Despite the fact that the number of days missed was not significantly different for both groups, students who missed school (due to absenteeism) would have received fewer hours of memory training and classroom instructions compared to their counterparts (Rothman, 2001).

Table 2. Number of days missed

Group		Statistic				
	N		Mean + SE	SD	Min	Max
Placebo	13		6.0 + 1.3	4.5	0	12
Treatment	15		7.9 + 1.6	6.1	0	19
All	28		7.0 + 1.0	5.4	0	19

Furthermore, the researcher was not blinded to the subject groups as there was a subtle difference between the user interfaces for the progressive computerized cognitive program and the basic computerized cognitive training program. The non-blinded nature of the researcher could have introduced some bias. In addition, the researcher utilized one of several computerized working memory training program and is therefore limited to making claims beyond this program. However, the training program was selected because it produced generalized effects in previous studies (Gathercole et al., 2003; Klingberg et al., 2005) and was designed to be used with younger students.

Suggestions for Further Research

There are a number of possibilities for future research. For this study, our population was low-achieving fifth graders in a primary school. The researcher selected one school and engaged all thirty fifth graders in the sole low achieving fifth grade class. Obtaining permission to have students engage in a study is a challenging task. However, a larger sample size makes the results of a study more generalizable (Gay et al., 2006). To this end, one suggestion for future research would be for researchers to engage a larger number of students to execute the study. In addition, future studies should utilize students from varied socioeconomic backgrounds. In this study, students practiced one hour per day, five days per week for five weeks. It seemed that this period and regularity of training was adequate to influence a training effect. However, future studies with low achievers could involve increased training time to influence session completion.

Summary

Individuals engage in the process of intellectual problem solving throughout life. Consequently, it is important that cognitive skills function well in order for them to effectively execute these mental activities. Working memory is important to the cognitive process as it is needed to temporarily hold information while simultaneously conducting the actions necessary to execute the requisite cognitive processes. However, research suggests that individuals have varied working memory capacity and may have difficulty learning as a consequence (Alloway et al., (2009) A number of researchers such as Gathercole et al. (2003), Passolunghi and Siegel (2004) and Zheng et al. (2011), have underscored the importance of working memory to mathematics and overall achievement. However, in addition to working memory, a number of factors such as (a) socioeconomic status, (b) academic factors, and (c) personal factors impact students and influence their academic achievement (Balfanz & Byrnes, 2006; Gottfried, 2010; Madyun & Lee, 2010; Stotsky, 2010).

While it is difficult to change some of the factors influencing academic achievement, research suggests that some factors can be enhanced through intervention (Godfried). For example Edlin et al. (2009), Klingberg et al. (2005) and Sinha (2005) suggest that brain training can enhance working memory. This enhancement is attributed to the idea of neuroplasticity which is the theory that an individual's brain can actually change as a consequence of training in a similar manner to how the muscles respond to exercise. The idea of improving the brain by training has influenced the development of a number of computerized cognitive training programs These programs have reportedly improved working memory capacity and attention in stroke patients, regular middle school students, children suffering from ADHD, healthy adults, and older adults (Brigman & Cherry, 2002; Holmes et al., 2009; Klingberg et al., 2005; Westerberg & Klingberg, 2007). The possibility that an increase in working memory capacity could result in improvement in cognition and could potentially enhance academic performance influenced the decision to examine whether low-achieving primary school students could benefit from use of these programs. Consequently, this study examined the interactions among working memory, computerized cognitive training and academic achievement.

Hypothesis one was tested to answer research question one which asked. What impact will computerized cognitive training have on the working memory capacity of fifth grade primary school low achievers?

Hypothesis 1

> There will be no significant difference in working memory capacity (as measured by the *Automated Working Memory Assessment* (Alloway, 2007) between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.

Hypotheses two and three were tested to answer research question two which asked. If working memory capacity significantly improved, to what extent will this improvement affect the mathematics achievement of fifth grade primary school low achievers?

Hypothesis 2

> There will be no significant difference in mathematics achievement (as measured by the Grade Four Literacy Test) immediately after training between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.

Hypothesis 3

> There will be no significant difference in mathematics achievement six weeks after training between low achievers who practiced on a progressive computerized cognitive training program as compared to low achievers receiving basic computerized working memory training.

A total of 30 fifth-grade students who met the inclusionary criteria were selected from a population of low-achieving primary school students. The students were pre-tested on four subtests of the *Automated Working Memory Assessment* (Alloway) namely: (a)

Verbal Short Term Memory (Digital Recall), (b) Verbal Working Memory (Listening Recall), (c) Visio Spatial Short Term Memory (Dot Matrix), and (d) Visio Spatial Working Memory (Spatial Recall). Memory testing was supervised by an experienced psychologist using the *Automated Working Memory Assessment* (Alloway, 2007). In addition to working memory assessment, participants were pre-tested by their grade teacher in mathematics achievement using the Grade Four Literacy Test. Therefore, information pertaining to working memory performance as well as mathematics scores before training was collected.

Students were randomly assigned to either the experimental or control group. The experimental group of students received progressive computerized cognitive training. The control group received basic computerized working memory training. Basic computerized working memory training differed from progressive computerized working memory training in that the difficulty level of the program was not increased to match the working memory capacity of the student (Klingberg et al., 2005). Training for both groups of student was conducted the same time each day by the class teacher at the participants' school. The duration for practice was one hour per day, five days per week for five weeks.

After the five weeks of training, all participants were post-tested in working memory using the *Automated Working Memory Assessment*. The working memory of the group receiving progressive computerized working memory training was compared to the group receiving basic computerized working memory training using a Repeated Measures *MANOVA*. Both experimental and control groups subjects showed improvements in working memory scores from the baseline pre-test to the post-test. Analysis of the multivariate tests suggests that there was significant difference Wilks Lambda (F = 2.880, p = .045) between the group receiving progressive computerized working memory training compared to the group receiving basic computerized working memory training. The null hypothesis was rejected.

Participants were post-tested in mathematics achievement immediately post training and at six weeks post-training using the Grade Four Literacy Test. The mathematics achievement of the group receiving progressive computerized working memory training was compared to the group receiving basic computerized working memory training using a Repeated Measures *MANOVA*. The experimental group demonstrated a greater improvement in mathematics achievement than the control group immediately post training. However, this improvement was not statistically significant (F = 2.719, p = .085). The null hypothesis in this case was not rejected. The experimental group also demonstrated a greater improvement in mathematics scores than the control group six weeks post training. However, this improvement was not significant (F = 2.719, p = .085). The null hypothesis in this instance was not rejected.

This study demonstrated that low-achieving primary school students could significantly improve aspects of their working memory capacity (as measured by the *Automated Working Memory Assessment* (Alloway, 2007)) through computerized cognitive training on working memory. The results of this study presented many options for further research. A larger sample size comprising low achievers from varied socioeconomic backgrounds may be useful in determining the effect of computerized cognitive training on the working memory and mathematics achievement of low achievers. Future studies with low achievers could involve increased training time or varied number of sessions. Based on the results of the study, it appears that computerized cognitive training supports working memory and could prove beneficial to low achievers. Educators could integrate computerized cognitive training as part of remedial program for students with working memory deficit.

Appendix A

Assent Form for Participation in the Research Study Entitled
The Effect of Computerized Cognitive Training on the Working Memory and Mathematics Achievement of Low Achievers

Funding Source: None.

IRB approval # **04301321**

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Nova Southeastern University
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What is a research study?

Ms. Shalette East needs to conduct a research study as part of her doctoral degree program. She is asking you to be in this research study. Research helps us learn new things. Only people who decide they want to help will be in the study. We'll tell you about the study and then you should take time to make your decision. You should talk to your parents or your guardian before you decide.

Why is this study being done?

This study is being done to see if low-achieving fifth grade primary school students would significantly improve their working memory capacity and academic achievement through training on the computer.

What will happen to me?

Dr. Leahcim Semaj will supervise the measurement of your working memory capacity using a computer program. In addition, you will be pre-tested in mathematics by your teacher. You will then be randomly assigned to either an experimental or a control group.

What are the good things about being in this study?

The experimental group of students will receive progressive computerized memory training. This computer program could assist you improve your memory and possibly help you improve your academic achievement. The control group will receive basic computerized memory training. If you are assigned to the control group, you will have the opportunity to work with the progressive working memory training program after the study.

Will being in the study hurt me?

No

How long will I be in the study?

The proposed duration for practice is five weeks, comprising 25 training sessions (one session per day) each 30-45 minutes in duration. Training will be supervised by your class teacher and will be conducted the same time each day after school. After the five weeks of training, measurement of your memory will be supervised by Dr. Leahcim Semaj. You will also be post-tested in mathematics achievement by your class teacher. If significant improvements are observed in the experimental group from pre-test to post-test, these students will be tested in working memory and mathematics for a third time.

Do I have other choices?

You can decide not to be in the study.

Will people know that I am in the study?

Persons directly related to the study, school officials, and the other participants in your class will know that you are in the study. If the researcher talks about the study she will not use your name.

Who can I ask questions?

If you have any question about the research, please speak with Dr. Tim Ellis or Mrs. Shalette East. Remember, you should also talk with your parents or your guardian about this study.

Is it OK if I say "No, I don't want to be in the study"?

You do not have to be a part of this study if you don't want to. No one will be mad or upset. If you change your mind once you start the study, you can stop being in the study.

Do you understand and do you want to be in the study?

I understand. All my questions were answered.

- ❑ I want to be in the study.
- ❑ I don't want to be in the study.

____

Your ID

_________________________________ __________

Your signature Date

_________________________________ __________

Signature of person explaining the study Date

Appendix B

Parent/Guardian Consent Form for Participation in the Research Study Entitled
The Effect of Computerized Cognitive Training on the Working Memory and Mathematics Achievement of Low Achievers

Funding Source: None.

IRB protocol #: **04301321**

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For questions/concerns about your research rights, contact:
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Site Information
Constant Spring Primary and Junior High School
Cassava Piece Road
Kingston 8
Jamaica

What is the research about?
You are being asked to let your child participate in a research study. This study is being used to determine whether low-achieving fifth grade primary school students would significantly improve their working memory capacity (as measured by the *Automated Working Memory Assessment*) through computerized cognitive training of working memory. The study will speak to two pertinent questions, what impact will computerized cognitive training have on the working memory capacity of fifth grade primary school low achievers, and to what extent will working memory skills learned under experimental conditions help fifth grade low-achieving primary school students improve their mathematics achievement. Thirty students will be randomly chosen from your child's class to participate in this study.

What will my child be doing?

Your child's working memory capacity will be pre-tested under the guidance of a psychologist using the *Automated Working Memory Assessment* (Alloway, 2007). Your child will be tested individually in a quiet place at school in two sessions within a single week. In addition to working memory assessment, your child will be pre-tested by their grade teacher in mathematics achievement using the Grade Four Literacy Test. Therefore, information pertaining to working memory performance as well as mathematics scores before training will be collected. Your child will be randomly assigned to either the experimental or the control group. Training will be conducted the same time each day by the class teacher at your child's school.

The experimental group of students will receive progressive computerized cognitive training. The proposed duration for practice on the computerized training program is five weeks, comprising 25 training sessions (one session per day) each 30-45 minutes in duration. Training will be supervised by the class teacher and will be conducted the same time each day after school.

The control group will receive basic computerized working memory training. In that the difficulty level of the program will not be increased to match the working memory capacity of the student. The proposed duration for practice on the computerized training program is five weeks, comprising 25 training sessions each 30-45 minutes in duration.

After the five weeks of training, your child will be retested in working memory using the *Automated Working Memory Assessment*. Additionally, your child will be post-tested in mathematics achievement using the Grade Four Literacy Test. Students' end of term mathematics scores will be collected and analysed to test for persistence.

Is there any audio or video recording?

No

What dangers are there for my child?

This study poses minimal risk to your child. However, the possibility of a loss of confidentiality exists because of your child's name being on the consent form. If you have any question about the research, please contact Shalette East, Ed.S. or Professor Tim Ellis Ph.D. Please note that you can also contact the IRB at the contact numbers indicated above regarding your rights.

What good things might come about for my child?

Students using the computerized cognitive training program will explore a tool which has been shown to enhance working memory. This exploration could assist low achievers and may prove useful in improving their academic achievement. Students in the control groups will have the opportunity to work with the progressive cognitive training program after the study.

Do I have to pay for anything?

No

Will my child get paid?

There are no payments made for participating in this study.

How will my child's information be kept private and confidential?

All information obtained in this study is strictly confidential unless disclosure is required by law. However, the IRB and my thesis adviser may review research records. Coded IDs will be created and used for data collection and analysis. The list linking the IDs will be kept in a fireproof cabinet at the researcher's home. This list will be destroyed three years after the close of the study. Furthermore, online data will be stored on a secured server and will be password protected.

What if I do not want my child to be in the study or my child doesn't want to be in the study?

You have the right to refuse for your child to participate or withdraw your child at any time. Your child may also refuse to participate or withdraw. If you do withdraw your child, or your child decides not to participate, neither you nor your child will experience any adverse effects. If you choose to withdraw your child, or he/she decides to leave, any information collected about your child **before** the date of withdrawal will be kept in the research records for 36 months from the conclusion of the study. You may request that it not be used.

Other Considerations:

If significant new information relating to the study becomes available, which may relate to your willingness to have your child continue to participate, this information will be provided to you by the investigators.

Voluntary Consent by Participant:

By signing below, you indicate that

- this study has been explained to you
- you have read this document or it has been read to you
- your questions about this research study have been answered
- you have been told that you may ask the researchers any study related questions in the future or contact them in the event of a research-related injury
- you have been told that you may ask Institutional Review Board (IRB) personnel questions about your study rights
- you are entitled to a copy of this form after you have read and signed it you voluntarily agree for (you and/or) your child to participate in the study entitled The Effect of Computerized Cognitive Training on the Working Memory and Mathematics Achievement of Low Achievers

Child's ID: ____

Parent's/Guardian Signature: ________________________________ Date:_____________

Parent's/Guardian ID: __________________________________ Date: _____________

Signature of Person Obtaining Consent: _______________________________

Date: ___________________________________

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