University of Missouri, St. Louis

IRL @ UMSL

Dissertations

UMSL Graduate Works

5-15-2015

Correlational Evidence between the Processing Speed Index, Coherent Motion Threshold, and Achievement Scores of Children With and Without Learning Disabilities

Thomas John LaRosa

University of Missouri-St. Louis, larosa_thomas@yahoo.com

Correlational Evidence between the Processing Speed Index, Coherent Motion Threshold, and Achievement Scores of Children With and Without Learning Disabilities

by

THOMAS J. LAROSA
Ed. S., School Psychology, University of Missouri – St. Louis, 2009
M. Ed, General Education – emphasis computer education, Lesley University Outreach – 1987
M.Ed., Elementary Counseling, University of Missouri – St. Louis, 1983
B.S., Elementary Education, University of Missouri – St. Louis, 1976

A dissertation Submitted to the The Graduate School of the University of Missouri – St. Louis
In partial fulfillment of the requirements for the degree

DOCTOR OF EDUCATION
in
TEACHING AND LEARNING PROCESSES

March 2015

<u>Advisory Committee</u>

Patricia Kopetz, Ed.D.
Chairperson

April Regester, Ed.D

Cody Ding, Ph.D.

Ralph Garzia, Ph.D.

Aaron Franzel, Ph.D.

Abstract

The purpose of this study was to determine the responses to three research questions. Is there an inverse relationship between PSI and CMT? Is a score on PSI associated with a child's performance on math fluency and math calculation? Is CMT associated with PSI on math fluency and math calculation? Academic performance in math was measured by tests of math fluency and calculation. The study investigated the likelihood that a child with a slow PSI will have a high coherent motion threshold (CMT).

The diagnostic status groups were comprised of 33 children from 2nd to 8th grades. The children were divided into three groups. One group of children with a learning disability in math only, one group of children with a learning disability in reading and in math, and one group of typically developing children. The group of typically developing subjects served as the control group, and the remaining two groups served as the experimental groups.

A correlational research model was used to determine if a relationship exists between Coherent Motion and PSI. A linear regression analysis was conducted to test the correlation between CMT and PSI to gather data relative to the first research question. An Analysis of Variance (ANOVA) was conducted to further test Hypothesis One. Results indicated that there is a moderate negative relationship that exists between PSI and CMT. It was further hypothesized that PSI is associated with a child's score on math fluency and math calculation, and that CMT is associated with PSI on math fluency and math calculation. A regression analysis was conducted to gather data relative to the second and third research question.

Analysis of Variance (ANOVA) was conducted and the findings suggested a moderate negative relationship exist between CMT and PSI. A regression analysis of variance (ANOVA) was used to show the relationship between math fluency and PSI, math calculation and PSI, and math calculation along with math fluency and PSI. The results revealed that a strong direct relationship exists between math fluency, math calculation and processing speed. A regression model was created to determine if PSI and CMT, along with being identified as disabled, can be used as a predictor for math fluency and math calculation scores. When CMT is combined with PSI and students identified as having a disability, the findings revealed that it was not a strong predictor of math fluency and math calculation abilities.

TABLE OF CONTENTS

Tables

Chapter 1

Introduction

There has been much concern over American school children's math abilities compared to children in other first world nations. A Key Message statement within the Principles and Standards of the National Council of Teachers of Mathematics (NCTM) states: "A solid mathematics education is essential for an informed public, our national security, a strong economy, and national well-being. All children should receive a quality mathematics education, regardless of sex, ethnicity, or race" (National Council of Teachers of Mathematics Key Message, 2004). While quality mathematics instruction is important, there are many children for whom achievement in mathematics remains a struggle. For students with a diagnosed learning disability in mathematics, this struggle is even more pronounced. To date, there has been no conclusive research indicating a specific cause of learning disabilities in mathematics, however some recent studies have suggested that visual impairments may be a factor. Boets, DeSmedt, and Ghesquiere (2011) and Sigmundsson, Anholt, and Talcott (2010) have suggested that children with a disability in math may have impairment in the magnocellular pathway (M-pathway) of the visual system. An impaired M-pathway will have a negative impact on the way a person processes visual information (Stein, 2001). Additionally, a study by Bull and Johnston (1997) revealed that children who were slow to execute math procedures were also weak in mathematics.

The primary purpose of this study was to determine the relationship between neurological functioning and academic performance in mathematics. This was accomplished by determining if there is a correlation between slow processing speed as measured by the Processing Speed Index (PSI) on the Wechsler Intelligence Scale for Children, Fourth Edition (WISC - IV) in children with a diagnosed learning disability, particularly in the area of mathematics, and impaired M-pathway. The study also explored the potential existence of a correlation between PSI and Coherent Motion

Threshold (CMT). The existence of a correlation between a low PSI score and high Coherent Motion Threshold (CMT) may indicate a deficit in the M-pathway that may play a role in some learning impairments.

The Department of Education's 28th Annual Report to the United States Congress (2004) states that 4.2% of the general population ages 6 through 21 received special education and related services due to their diagnosis of specific learning disabilities (SLD) in reading, math, and/or written language. Part of the same report discusses the results of the Special Education Elementary Longitudinal Study (SEELS) findings. SEELS resulted from provisions in the 1997 Reauthorization of IDEA, and was conducted for the Office of Special Education Programs (OSEP) between 2000 and 2006. SEELS findings revealed that more than two-thirds of the children aged 6 to 12 have disabilities in the area of reading comprehension, while 40% have disabilities in the area of math calculations. These results were based on test data using the Woodcock-Johnson III subtests of Passage Comprehension and Math Calculation. The report concludes that 29.1% of the children, ages 14 through 21 with SLD, dropped out of school during the 2003-2004 school year. In other words, more than one-fourth of the children diagnosed with SLD do not graduate from high school. With the majority of children receiving special services in reading, it is easy to understand why there has been a large focus on research studies into the causes of reading comprehension deficits.

There has been a considerable amount of research in topics related to reading over the past 50 years that have led to some major advances in the understanding of reading disorders (RD) (Makita, 1968; Galaburda & Kemper, 1979; Castles & Coltheart, 1993; Fiez & Petersen, 1998.) Some of the research focused on visual processing and the impact the M-pathway has on reading (Stein & Walsh 1997; Stein &Talcott, 1999; Sperling, Lu, Manis, & Seidenberg, 2003; Sperling et al., 2005).

A number of studies, including Cornelissen, Richardson, Mason, Fowler, & Stein, 1994; Stein & Walsh, 1997; Stein &Talcott, 1999; Stoodley, Talcott, Carter, Witton, & Stein, 2000; Stein, 2001; and Sperling, et al., 2003, revealed that a deficit in the M-pathway can have a negative impact on reading ability. In fact, these researchers suggest that an M-pathway deficit may have a causal effect on dyslexia, (Talcott, Hansen, Assoku, & Stein, 2000). According to Shaywitz, et al. (2008), developmental dyslexia is often referred to as simply: "dyslexia." The reading deficit condition may also be referred to as a specific reading disability. Shaywitz (2008) defines dyslexia as: "… an unexpected difficulty in reading. Unexpected refers to children and adults who appear to have all the factors necessary to become good readers: intelligence, motivation and exposure to reasonable reading instruction – and yet struggle to read" (p. 454). The research conducted by Stein and Talcott (1999) related developmental dyslexia to an impaired magnocellular stream (M-pathway), which impacts the ability to read. They developed a hypothesis that a dyslexic reader may have a lower sensitivity to visual and auditory stimuli due to an impaired M-pathway and this may explain their visual problems when the reader attempts to read. NOTE: Recent evidence has shown that the magnocellular system and the dorsal stream are separate concepts and entities. The magnocellular system stretches from the retina to the primary visual cortex. There the inputs from other systems intermingle and mix. From the primary visual cortex it is possible to trace two processing streams to higher level visual processing centers. It is the dorsal of these two streams that provides input to Area MT, an important center for processing of visual motion stimuli. However, for the purposes of this paper, we will continue to use the traditional term M-pathway and through its assumed contribution to the dorsal stream, motion detection and predominate use in the literature at this time.

Stein and Talcott's research was important for understanding the dyslexic reader, however, during the same period of time, 40% of the special education population scored below the 25th percentile on math calculation (Blackorby, Chorost, Garza, & Guzman, 2007) and there have been few significant research studies on understanding math disabilities. The negative impact of an M-pathway deficit on reading comprehension is now being considered as having possible implications for difficulties in mathematics as well (Sigmundsson et al., 2010 & Boets et al., 2011.)

Despite this consideration, the research focusing on potential causal factors for mathematics disabilities is severely lacking. Noel (2000) found that from 1974 to 1997, the internet search engine: Psych-Info, listed only 28 articles on mathematics learning disabilities (MLD), while more than 700 articles were listed for reading disabilities. In preparation for this dissertation study, the author conducted searches of relevant articles utilizing the Education Full Text-EBSCO Host database (2012). This database included educational articles published from 1983 to present. The search found 1,839 published articles in the area of reading disabilities, and only 87 articles published in the area of math disabilities. Geary, Hamson, and Hoard (2000) suggest one possible reason that research of disabilities in mathematics has been slow may be due to the complexity of the math domain, and the wide array of cognitive deficits that may result in this form of learning disability.

Before discussing the possible causation of math disabilities, it is important to define what is meant by a math disability. The terms mathematics disability, mathematics difficulty, nonverbal learning disability, and arithmetic disability are often used interchangeably to describe disabilities in mathematics (Vukovic & Siegel, 2010). Many educators use the discrepancy formula to identify students with a learning disability in math (Forness, Sinclair, & Guthrie 1983). The discrepancy formula uses standardized achievement tests in combination with an intelligence measure (IQ). Many students have a significant discrepancy between their cognitive ability and their actual math achievement level. These students' cognitive level often falls within the average range of intelligence while their math achievement falls below average, often at the borderline level. According to Geary (2004), a lower score in the 25th percentile on a math achievement test, and a low average to average or higher intelligence test score are typical criteria for the identification of MLD. Geary (2004) strongly feels that children who have lower than expected achievement scores in math for two or more successive years often have some form of disability in math, and a MLD diagnosis is appropriate. For the purposes of this study, a math learning disability will be defined as a child having met the state and district criteria for a learning disability in mathematics.

Students that have a learning disability in mathematics are often found to have a learning disability in reading as well. Dyslexia and dyscalculia have a high-rate of co-morbidity among students with a learning disability (Sigmundson et al., 2010). Dyslexia has been associated with reduced sensitivity to coherent motion stimuli (Cornelissen, Richardson, Mason, Fowler, & Stein, 1995). Sigmundsson et al. (2010) examined whether deficits in sensitivity to visual motion are present in children with poor mathematics skills relative to those of typically developing children of the same age. Their study examined the visual motion sensitivity of children whose mathematics skills fell in the bottom 10% of the study group to that of children whose math skills fell in the highest 10% of the group. The study found that children at the bottom 10% of their class in math ability demonstrated lower sensitivity to coherent motion than the age-matched control group of children in the highest 10% of math skills. This finding suggests that, just as visual processing deficits in the M-pathway impact reading, they may also impact one's performance in mathematics. Sensitivity to visual motion was measured by the minimum number of dots moving in a common direction amid moving random dot patterns. These findings suggest there is an association between the M-pathway and math skills.

Current studies have begun to appear in the literature that investigate whether children with impaired skills in mathematics have deficits in the M-pathway (Boets et al., 2011). The M-pathway begins in the retina of the eye (ganglion cells) and carries the image the eye sees to the brain through the lateral geniculate nucleus (LGN). The anatomy of the M-pathway is characterized by large retinal ganglion cells. The cells have larger receptive fields, they are sensitive to high temporal frequencies and low to medium spatial frequencies, and they also show high sensitivity to luminance contrasts (Hammarrenger, Lepore, Lippe, Labrosse, Guillemot, & Roy, 2003*)*. M-pathway cells have thicker axons, and can transmit information faster than P- smaller diameter ganglion cells. These larger ganglion cells are distributed more in the peripheral retina. In contrast, the P or parvocellular pathway has retinal ganglion cells that are smaller in size, have smaller receptive fields and are more concentrated in the central retina. These cells are also chromatic and are responsible for color vision (red/green) and fine visual acuity. There is a third category of retinal ganglion called koniocellular (K-cells), smaller than P-cells and are responsible for blue color vision. The perception of coherent motion can be used to determine the sensitivity of the magnocellular system (Cornelissen, Richardson, Mason, Fowler, & Stein, 1995). Magnocellular processing in the visual system may be measured by using a random dot kinemetogram, which gives a measure of motion coherence threshold (Milne, Swettenhanm, Hansen, Campbell, Jeffries, & Plaisted, 2002). Milne et al. (2002) state: “Motion coherence threshold is the ability to detect coherent motion from an array of randomly moving dots” (p. 257). Individuals with a low sensitivity to coherent motion have deficits in the magnocellular system (Cornelissen et al., 1995).

In a similar study, Boets et al., (2011) investigated the association between coherent motion sensitivity and single-digit subtraction and multiplication. Their work found an association between coherent motion and subtraction performance. However, in multiplication, no association was found.

The study consisted of 38 typically developing children. All participations had typical intellectual ability (range 87 – 134) and normal word reading skills (range of 85 – 125). The findings revealed a significant association between coherent motion sensitivity and speed of subtraction, suggesting that children who are less sensitive to coherent motion are slower in solving subtraction problems which all involved borrowing and had a minuend between 11 and 18 (Boets et al., 2011).

Based on the work of Sigmundsson et al. (2010) and Boets et al. (2011), this study compared the PSI scores of children with a learning disability in math (only) and those with a disability in both math and reading to that of typically developing children (three groups total). Included in this chapter is the background for the study, purpose of the study, need for the study, a statement of hypothesis, research questions, the scope of the study, and the significance of the study. Chapter Two provides an extensive review of the literature related to the study. Chapter Two covers the current research examining the impact of the M-pathway on learning, and the latest research on math disabilities. Chapter Three presents the research procedures and methodology with a description of the tests administered to each of the subjects included in the study. An analysis of data is presented in Chapter Four. The concluding chapter, Chapter Five, provides a summary of the findings and presents recommendations for future research, and conclusions.

Background of the Study

Much of the research conducted on children with learning disabilities in mathematics has been focused on the area of arithmetic. Arithmetic is defined by the Merriam-Webster online dictionary as “a branch of mathematics that deals usually with the nonnegative real numbers including sometimes the transfinite cardinals and with the application of the operations of addition, subtraction, multiplication, and division.” Arithmetic consists of the basic skills in addition, subtraction, multiplication and division, and in the ability to add, subtract, multiply and divide with and without renaming whole numbers (Davenport, 1999). The term "math" or "mathematics" is synonymous with "arithmetic" in this study.

While there has been relatively little research conducted in mathematics when compared to reading, there has been some significant research in the field of math disabilities. Some cognitive tasks that appear to be related to math achievement in children include counting rate (articulation) and the rapid naming of digits (RND) (Denckla & Rudel, 1976; Norton & Wolf, 1991). The rapid naming of digits is equivalent to the rapid naming of words in reading. Gersten and Chard (1999) state that number-sense in math is the equivalent to phonemic awareness in reading. They strongly feel that for children to succeed in math, they must have an understanding of what numbers mean, and engage in some form of mental mathematics. Although their findings focused on skills necessary to be successful in math, they did not study children who were unsuccessful in math. Related research seeks to understand the ability of children to learn mathematics, and to determine the quantitative competencies of children with a learning disability (Geary, Brown, & Samaranayake, 1991; Geary, Saults, Liu, Hoard, 2000; Geary, Hamson, & Hoard, 2000; Geary, 2004).

Geary. (1991) argued that, "addition facts are more likely represented in a semantic network, and deficits in arithmetic fact retrieval also accompany certain forms of dyslexia and aphasia" (p. 796). The researchers concluded that the retrieval of basic information from the long-term memory was a main factor in learning mathematics. Geary, Hoard, Byrd-Craven, & DeSoto (2004) conducted a study of first grade, third grade and fifth grade math disabled (MD) students. They found that in all grades the children with MD showed a deficit in working memory. This suggests that children with math disabilities may have a weak memory retrieval system.

According to Dempster (1992) and Gathercole & Baddeley (1993), improvements in working memory during childhood development are attributed to faster processing speeds. Kail (1992) examined the role of processing speed and the role of long- memory in young children ages 5 to 13 years old. Kail found that an increase in processing speed can predict the amount of long-term memory for phonological representations.

Research by Bull and Johnston (1997) revealed that processing speed might be another indicator of math abilities. They studied elementary children and their mathematics skills, and found that processing speed via a visual route was a strong predictor of arithmetic ability. Their findings indicated that, while there was a strong correlation between short-term memory and math ability, other factors were also to be considered. Their research concluded that automatic, basic arithmetic facts might result from a processing speed deficit. Bull and Johnston's (1997) conclusion suggests that the speed of processing may be significant in the explanation of math deficits among children with MLD.

Processing speed is the ability to perform cognitive tasks in a fluent and fast manner, while one is concentrating and focused on a task (Flanagan & Kaufman, 2004). Flanagan and Kaufman (2004) further discussed processing speed using the Cattell-Horn-Carroll (CHC) theory of cognitive abilities, and stated: "Attentive speediness encapsulates the essence of *Gs*, which is measured typically by fixed-interval, timed tasks that require little in the way of complex thinking or mental processing" (p. 304). A main factor in the ability to process information is the small capacity of the short-term or working memory. The speed of processing is crucial, because an increase in processing speed can decrease the pressure on one's short-term memory, which in turn, opens it up for more complex cognitive activity. The WISC-IV includes three subtests for processing speed. Two of these subtests (Coding and Symbol Search) yield a Processing Speed Index (PSI) score.

Both subtests are conducted in the visual mode. Processing speed measures one's ability to focus attention, and too rapidly scan, discriminate between, and sequentially order visual information. It requires task-persistence and the ability to work under a time constraint, as well as fine-motor coordination (Flanagan & Kaufman, 2004). Based on the Flanagan & Kaufman (2004) definition of processing speed, for children to be fluent in math, they need to have good processing speed.

Math fluency is the ability to recall basic math facts in a rapid manner. In order for children to grasp higher skills in math, it is imperative that they are able to recall basic math facts with quick accuracy (Axtell, McCallum, Bell, & Poncy, 2009). Fluency is basically the same concept in both math and reading (Pikulski & Chard, 2005); it requires a functional skill (decoding or algorithmic skills). After the functional skill is learned and becomes routine it is referred to as automaticity (Axtell et al., 2009). According to Bull and Johnston (1997), "Children with arithmetical difficulties were slow in the speed of executing operations, such as the speed of identifying numbers, speed of matching numbers and shapes, speed of perceptual-motor performance, and the speed of executing arithmetical procedures" (p. 22). Based on the findings of Bull and Johnston (1997), processing speed is a strong predictor of mathematics ability. The speed that one can process information can be seen in a child solving the basic math facts, because they are over-learned material.

In addition, Magnetic Resonance Imaging (MRI) has been used to study the brain, as basic math facts are being learned. MRIs have shown an actual change in brain activation patterns that occurs as math facts are learned. Research indicates that, through instruction and practice, processing of math facts moves from the quantitative area in the brain to an area related to automatic retrieval. Findings conclude that moving from the quantitative area to an area related to automatic retrieval assists individuals in the computation of complex math problems (Delazer, Bartha, Brenneis, Locky, Trieb, & Benke 2003).

If a correlation between math and reading exists, could factors leading to deficits in reading performance also lead to deficits in math performance? Sigmundsson, Anholt, and Talcott (2010) offered:

> Given the overlap between the cognitive requirements of reading and mathematics and the high co-occurrence rates of impairment between these educational spheres and with other developmental disabilities associated with impairments of visual motion processing …predict that dyscalculia would be associated with reductions in sensitivity to coherent motion (p. 248).

A study conducted by Stein and Walsh (1997) concluded that children with a disability in reading have a basic impairment of their visual processing systems. Such research demonstrates a significant relationship between poor reading abilities and part of the visual pathway known as the M-pathway (Stein, 2001). Stein found that the layers of the M-pathway in the lateral geniculate nucleus (LGN) were abnormal, thus reducing their sensitivity to motion.

If there is a correlation between reading disabilities and visual processing, is there a correlation between visual processing and one's ability to perform in mathematics? The most recent work of Sigmundsson, Anholt, & Talcott, **(**2010) suggests that a correlation does exist.

Research has shown that children, as well as adults, with disabilities in reading perform differently from control groups in low-level visual tasks (Willows, Kruk, & Corcos, 1993). Cornelissen, et al. (1995) revealed that children with disabilities in reading have difficulty detecting coherent motion in random dot kinematograms. (NOTE: Random dot kinematorams (RDK), where the percentage of dots that move together in the same direction is varied while the remaining dots move randomly is the most commonly used measurement of motion coherence thresholds. In this paper I will use CMT to represent coherent motion thresholds). CMT involves no reading or written expression. The lower an individual's sensitivity to coherent motion, the faster is one's ability to detect motion, and the more robust the M-pathway. The higher one's sensitivity is to coherent motion, the slower is one's ability to detect motion, and the weaker is the M-pathway.

Statement of the Problem

Although studies confirm a relationship between visual processing (as measured by sensitivity to coherent motion) and math abilities, the Boets et al. (2011) study indicated that visual processing did appear to interfere with subtraction, but not with multiplication performance. Bull and Johnson (1997) suggested that processing speed is a strong indicator of a child's ability in overall mathematics. These results raise the possibility of a relationship between the speed of processing visual information and a variety of math skills. The work of the above mentioned researchers begs the question, does a child with a low processing speed have, as a result, a high CMT (or weak motion sensitivity)? What is the impact of a high CMT on a child's measured math calculation and math fluency?

Purpose of the Study

The purpose of this study is to determine the relationship between neurological functioning and academic performance in the area of mathematics. Neurological functioning will be measured by CMT scores and PSI scores. Academic performance in math proficiency will be measured by tests of math fluency scores and math calculation scores. The study will investigate the likelihood that a child with a slow PSI will have a high CMT. High thresholds or low sensitivity to coherent motion would suggest a deficit in the M-pathway, which is suspected to result in an individual's difficulty to process routine information. Such a deficit can lead to significant problems in learning. The Sigmundsson et al. (2010) and Boets et al. (2011) studies support a connection between processing speed and math performance. Their research would suggest that children with a deficit in the M-pathway will have difficulty developing pattern recognition and visual number relationships, and additionally, they may have difficulty with math fluency and math calculation. Therefore, a deficit in the M-pathway might negatively impact an individual's ability to succeed in math.

Research Question

This study will explore the following research questions:

Is there an inverse relationship between PSI and CMT?

Is a score on PSI associated with the scores on measures of math fluency and math calculation?

Is a score on PSI combined with CMT associated with scores on measures of math fluency and math calculation?

To determine if a relationship exists between a child's M-pathway and PSI, the M-pathway will be assessed by testing children's sensitivity to coherent motion, which is indicated by their CMT scores. If a positive correlation is found between a child's CMT scores and math calculation and math fluency scores, the child who demonstrates higher CMT scores may likely score lower on math fluency and math calculation measures when compared to the typically developing child's scores. The same should also be true for PSI. If a positive correlation is found between PSI and math fluency and math calculation scores, the child who demonstrates a lower visual processing speed (PSI) may likely score lower on both math fluency and math calculation subtests. If a positive correlation is found between CMT and PSI scores, the child with higher CMT scores should demonstrate a lower PSI when compared to the typically developing child's scores. A positive correlation between a child's CMT and PSI may suggest a deficit in the M-pathway.

This study will compare results of three groups of children on assessments of PSI and CMT. Groups will include 2nd through 8th grade children and will be arranged as follows: Group 1 will include children who are typically developing in reading and mathematics; Group 2 will include children with a diagnosis of learning disabilities in math only; and Group 3 will include children with diagnosed learning disabilities in both reading and math.

Research Hypotheses

This study will examine the possible existence of a relationship between PSI and sensitivity to coherent motion. The Sigmundsson et al. (2010) study revealed that children struggling in math had a high sensitivity to coherent motion. These results were similar for children with reading disabilities. The Boets et al. (2011) study revealed an association between sensitivity to coherent motion and difficulty with subtraction performance. Both studies found a positive association between coherent motion sensitivity and math performance. Based on their findings, the following hypotheses will be tested:

- Hypothesis #1: There is an inverse relationship between PSI and CMT
- Hypothesis # 2: There is a positive relationship between a PSI score and the scores on measures of math fluency and math calculation.
- Hypothesis #3: When a low PSI score is combined with high CMT a positive relationship will result with scores on measures of math fluency and math calculation.

Scope of the Study

Students for this study were drawn from two public school districts in the suburbs of a large Midwestern metropolitan area, one private school, one urban school, and one rural school district. Three groups of elementary children in 2nd through 8th grades were selected for this study. Group 1 included children who were typically developing in reading and mathematics; Group 2 included children with a diagnosis of learning disabilities in math only; and Group 3 included children with diagnosed learning disabilities in both reading and math.

Limitations of the Study

This study included 33 children in a Midwestern metropolitan region that included suburban, urban and rural school districts. Because of the small sample, the results must have a conservative interpretation. A restrictive cutoff criterion was used in the selection of the participants for this study, chosen in an attempt to avoid children with math deficits due to poor instruction and chronic absences. As Geary, Hoard, Nugent, and Byrd-Craven (2007) stated, “Use of a restrictive cutoff criterion identifies children with pervasive and often severe math cognition deficits and underlying deficits in working memory and speed of processing, whereas use of a lenient criterion identifies children that may have more subtle deficits in a few math domains” (p. 1357).

The children selected for this study were properly assessed by a school psychologist, under the conditions described in the manual of the tests administered. Every child diagnosed in each district met all criteria required by the State and its respective school districts for a MLD.

Significance of the Study

Geary (2004) commented that, although there have been a few advances in the understanding MLD, there is a lot that remains to be known about the ability to learn math. Further he stated: “…relatively little research has been conducted on the ability of children with MLD to solve more complex arithmetic problems and even less has been conducted in the other mathematical domains” (p. 13). Research that can access the cognitive abilities and processes that allow an individual to think and reason mathematically, may result in better teaching methods, and ultimately lead to students’ developing a strong understanding of mathematical concepts.

It is necessary that educators and psychologists have an understanding of children with a math disability in order to better identify them and provide services to these children (Shepard, 1994). It is equally essential that teachers have a better understanding of children with a math disability in order to meet their unique needs. Without appropriate identification and proper services for these children, they may never develop their true learning potential (National Association for the Education of Young Children, 2009).

The results from this study can impact not only classroom and resource teachers, but parents and especially children. The results of this study are intended to help all educators gain a better understanding of processing speed and its impact on the learner, thereby gaining a better understanding of learning disabilities, in general.

Having a clearer understanding of the neurological processes of the visual processing system will provide educators with a deeper understanding of the relationship between the visual system and the brain in the learning process. This, in turn, can assist in the development of more appropriate curricula for both children with and without MLD.

Summary

During the past 50 years there have been relatively few studies on the causation of math disabilities, when compared to the number of studies conducted on reading disabilities. Much of the research conducted on children with a learning disability in mathematics has focused on basic arithmetic computation. Geary, 1991 has argued that deficits in arithmetic fact retrieval also may accompany certain forms of dyslexia.

Much of the research conducted on math in the past 20 years has focused on mathematics and the memory system. A number of these studies concluded that long-term memory was a main factor in learning mathematics (Dempster, 1992; Gathercole & Baddeley, 1993; and Kail, 1992; Geary, Hamson, & Hoard, 2000; and Geary, 2004). Gathercole & Baddeley (1993) found a correlation between processing speed and working memory. Kail’s (1992) research suggests that an increase in processing speed may predict the amount of long-term memory for phonological representations.

Bull and Johnston (1997) found that when reading ability was controlled for, arithmetic ability was best predicted by one's ability to process information. They concluded that children who have difficulty in automatic recall of basic math facts may also have a processing speed deficit. Therefore, the speed of processing may be significant in the explanation of math deficits among children with MLD.

Stein and Walsh (1997) concluded that children with a disability in reading have a basic impairment of their visual processing systems the M-pathway (Stein, 2001). Stein found that the layers of the M-pathway in the lateral geniculate nucleus (LGN) were abnormal, thus reducing their sensitivity to motion.

The purpose of this study is to determine the relationship between neurological functioning and academic performance in the area of mathematics. Neurological functioning will be measured by CMT scores and PSI scores. Academic performance in math proficiency will be measured by tests of math fluency scores and math calculation scores. Children having a high threshold sensitivity to coherent motion would suggest a deficit in the M-pathway, which is suspected to result in an individual's difficulty to process routine information. Such a deficit can lead to in impediments to learning efficiency. The Sigmundsson et al. (2010) and Boets et al. (2011) studies support a connection between processing speed and math performance. Their research would suggest that children with a deficit in the M-pathway will have difficulty developing pattern recognition and visual number relationships, and additionally, they may have difficulty with math fluency and math calculation. Therefore, a deficit in the M-pathway might negatively impact an individual's ability to succeed in math.

To gain a better understanding of the study, chapter two will provide a more in-depth review of the past research relating to the learning of mathematics, dyslexia, processing speed, working memory, and the magnocellular pathway. The literature review will provide a foundation for this study. Chapter Two will analyze previous studies that are related to this study to show how this study is adding to the understanding of neurological functioning and academic performance in the area of mathematics.

Chapter 2

Review of the Literature

Overview

Many similarities can be found between reading and mathematics. Both require the automatic recall. In reading, a child must learn and memorize commonly found words in the English language. These commonly found words are often referred to by educators as high frequency words. In math, the child has to learn basic math facts. These are simple addition, subtraction, division and multiplication facts that are common components found in complex problems. Both require automatic recall for success. Reading and math also require the child to be fluent. Reading fluency is a necessary requirement for good comprehension; math fluency is the ability to respond quickly and accurately to basic math facts. Fluency in reading concerns the speed and accuracy at which one reads text; however, it does not mean that the person comprehends what they are reading (Pikulski & Chard, 2005). Fluency in math is the ability to accurately and quickly solve math problems. In reading, one is required to use decoding skills and in math one is required to use algorithmic skills. Burns (2005) explains that math fluency is evident when a child can solve a problem faster through recall than performing a mental algorithm. Therefore, fluency is the same in both reading and math because it requires the functional skill of decoding in reading and algorithmic skills in math but not the comprehension.

The causation of dyslexia has been extensively researched and debated during the past half-century (Pavlidis,1981; Wimmer, 1993; Nicolson, 1996). There is a substantial amount of literature, which supports phonological theory of dyslexia and gives primary concern to the auditory system (Shaywitz, 1996; Frost, 1998; Ziegler & Goswami, 2005). Also, there is a substantial amount of recent literature supporting the magnocellular theory, which suggests that a deficit in the visual pathway impacts reading ability and gives primary concern to the visual system (Cornelissen et al., 1994; Stein & Talcott, 1999; Stein, 2001; Talcott et al., 2000; Hulslander, et al., 2004, Boden & Giaschi, 2007). During recent years, researchers have begun to examine the visual pathway's influence on math ability in children, especially arithmetic abilities (Boets et al., 2011; Sigmundsson et al., 2010).

This study examined the impact of PSI and the M-pathway to better understand the role visual processing may play in math performance, particularly with respect to children who have been diagnosed with MLD. This chapter presents a review of the literature on the visual processing system and mathematics that has led to studying the impact of visual processing speed on math performance. The chapter will address each of the following:

- Learning Disabilities Defined
- Basic Components in Arithmetic during the Developmental Years
- Number Sense
- Counting
- Number Comprehension
- Simple Addition
- Simple Subtraction
- Direct Retrieval
- Math Fluency
- Processing Speed
- Working Memory
- Coherent Motion
- Neurological Similarities in Reading and Math

- The Neurological Component of Mathematics
- The Magnocellular Theory

Learning Disabilities Defined

For the purposes of this study, a learning disability in math is defined as demonstrating a history of poor mathematics achievement and meeting the state and district criteria for a learning disability in math. A learning disability in math is often referred to as Dyscalculia (Kosc, 1974). The term dyscalculia refers to someone lacking the ability to perform arithmetic operations of addition, subtraction, multiplication, and division of whole numbers (Butterworth, 2010). Dyscalculia has also come to mean someone who lacks the basic understanding of numbers as abstract concepts to of comparable quantities and is used comparably to the term dyslexia to describe reading difficulties of words (Butterworth, 2010).

The State of Missouri allows two methods for public agencies to use when determining whether or not a student has a specific learning disability (State of Missouri Guidance for Identification of SLD, 2008). The first method is responsiveness to a scientific, research-based intervention process, also known as response to intervention (RtI), or problem-solving method of identification. The other method consists of a pattern of strengths and weaknesses, which is also known as the "discrepancy model." For either method, the evaluation process must draw upon information from a variety of assessment tools and strategies, and may not rely on any single procedure for determining eligibility for special education and related services. Examples of sources of information used during the evaluation process include formative and summative assessments, characteristics exhibited of a SLD, and ongoing concerns.

The discrepancy model was reinforced as the primary criterion for LD identification (Chalfant & King, 1976), and became, over time, almost the exclusive procedure used for LD eligibility determination (Frankenberger & Fronzaglio, 1991; Mercer, Jordan, Allsopp, & Mercer, 1996). Students in this study, who were identified as having a specific learning disability in MLD and/or reading disability, were identified using the discrepancy model.

Basic Components in Arithmetic during the Developmental Years

The development of the basic components in arithmetic is provided, so that the reader has an understanding of typical progression of math development in children. In order to understand learning disabilities in math, it is important to understand the basic components of arithmetic that a typically developing child acquires for a strong foundation in math.

Just as one needs to have competent phonemic awareness to be a proficient reader, to understand mathematics, one has to gain a strong understanding of numbers. Learning about numbers is a complex process that begins long before a child enters the school system. As children begin to develop a sense about numbers, they must learn number words (e.g., one, two, and three). The child then can begin to count. As children begin to count, they begin learning the Arabic number symbols and their sequences, and then learn to translate between the oral, written and symbolic representations of numbers. Once these skills are developed, they typically can learn to add and subtract numbers and develop fluency in math. If children are slow in the ability to process information in a quick manner, they may be slow in their ability for number retrieval, counting, and performing simple addition and subtraction (Geary, 2004).

Number Sense

Number sense refers to a child's awareness and understanding of numbers. Gersten and Chard (2001) concluded: "Number sense is an emerging construct that refers to a child's fluidity and flexibility with numbers, the sense of what numbers mean and an ability to perform mental mathematics and to look at the world and make comparisons" (p. 3). Number sense is not defined by all researchers exactly the same (Gersten, Jordan, & Flojo, 2001). However, most researchers do agree that number sense is the child's basic understanding of number relationships, recognizing numbers, counting, recognizing number patterns, and how numbers relate to each other (Jordan, Kaplan, Oláh, & Locuniak, 2006). Most children develop number sense in their home environment through parental, sibling, and family interactions before they enter kindergarten. Studies suggest that young children have a sense of numerical magnitudes (Jordan et al., 2006). This understanding of numbers begins before children enter kindergarten and continues through the second grade. A study by Xu, Spelke, & Goddard (2005) suggests that number sense develops during infancy. These findings suggest that a young child, weak in number sense, may have difficulty understanding simple mathematical concepts such as addition or subtraction in later years. As number sense begins to develop in the typical young child, the child begins counting.

Counting

Another basic component of math is counting. A four-year-old child who can count to 50 may not comprehend the rules of counting, just as a child who can recite the alphabet may not understand that letters have sounds that are used to form words. Geary (2004) described the five basic rules and principles that involve counting, which were developed by Gelman and Galistel (1992). The first three rules entail counting; the fourth rule is concerned with what to count; and the fifth rule is a combination of the other four principles.

Further, Geary et al. (2001) observed that children with developmental dyscalculia are usually able to count objects and recite numbers correctly when they are counting. Most children with dyscalculia understand the principles of stable-order, cardinality, and abstraction. First- and 2^{nd}-grade children with dyscalculia frequently made errors on order-irrelevance (Geary, Hoard, & Hamson, 1999). Order- irrelevance is the order in which the objects within a set are counted

(Baroody, 1993). This would suggest that children with dyscalculia do not have an understanding of the basic principles of counting. As the child learns to count, the child begins to develop an understanding of numbers. This understanding of numbers is referred to as Number Comprehension.

Number Comprehension

Number comprehension requires the child to understand the meaning of the processed numbers and to translate the numbers from one representation to another (e.g., “twenty” to “20”). This can be seen in young children when they understand that three is greater than two (Geary & Hoard, 2002). Young children begin to develop number comprehension when they hear people in their lives use numbers. For example, their mother may say “There are only three apples left,” or “set the table for four.” Later, children realize that four can be written as an Arabic numeral as “4.” This is the beginning of number comprehension. As it continues to develop in children, they will need to distinguish that the “2” in 20 refers to two sets of tens, and the “2” in 200 refers to two sets of hundreds. It is important to note that children first learn number words ("one," "two," and "three"…), and then couple them with their Arabic numeral counterpart.

Children with a MLD will frequently exhibit problems with place value. They will have trouble transcoding “forty-five” and make it “405”. They will have difficulty grasping the concept that “45” means four sets of ten and five ones. As children enter school, they experience changes in their problem solving strategies, as they learn to construct more efficient counting strategies. As the child enters school the concept of addition is introduced (Geary et al., 2002).

Simple Addition

There has been an extensive amount of research conducted on the cognitive abilities associated with the development of simple arithmetic skills in young children over the past quarter of the century (Ascraft, 1982; Carpenter & Moser, 1984; Seigler, 1996). Geary (2001) noted that changes can be seen in children's problem-solving abilities, as they begin to develop a deeper understanding of the concepts of arithmetic and counting. When children first learn how to perform a simple addition problem, most children count each of the addends, often using their fingers (as cited in Siegler & Shrager, 1984). This is known as the finger counting strategy. There are some children who verbally count out the addends, without the aid of their fingers, which is known as the verbal counting strategy.

Geary (2001) describes the two most commonly used counting procedures employed by young elementary children. The first counting procedure is named the "min", and the second is called the "sum" procedure (Fuson, 1982; Groen & Parkman, 1972). The procedure may be referred to as count-on strategies. Referred to as the most common, the "min procedure" requires the child to state the larger-value addend, and then count out the value of the smaller addend (e.g., 4 + 3 using the min counting strategy 4, 5, 6, and 7). A few children state the smaller addend, and then count out the larger addend. This is referred to as the 'max' procedure. A child using the sum procedure would count out each addend starting from one (Geary, Hamson, & Hoard, 2000). It is common for young children to understand the mathematical operation of addition, even though they may not be capable of writing a written equation. As the child continues to learn mathematics they then develop an understanding of subtraction (Copley, 2010).

Simple Subtraction

The process of learning subtraction is very similar to that of learning addition. Young children begin learning subtraction using both overt and covert counting procedures. Instead of counting up, as one does in addition, they learn to count down, from the minuend, an amount equal to the subtrahend. The other method some children use is to count on from the subtrahend until the minuend is reached. As children begin calculating basic subtraction problems, they begin to learn set procedures for subtraction, just as they did for addition. As the child's understanding of counting develops, there is a shift from sum and max procedure to min counting (Geary, Bow-Thomas & Yao, 1992; Geary & Hoard, 2002). Prior to kindergarten, young children typically use very overt counting procedures. As they start school and are given proper instruction and practice, they move to more advanced and efficient counting procedures. As they develop and become competent with performing basic addition and subtraction calculations by counting, they begin to transition to direct retrieval (just knowing the answer) of simple math problems (Pellegrino & Goldman, 1987; Geary et al., 2001; Geary et al., 2002).

Geary et al. (2001) states that research conducted in the United States and abroad all yielded similar findings concerning simple addition and subtraction of children with a math disability. Studies found that common among children with developmental dyscalculia are procedural and memory-based deficits. Only in the past two years does research seem to consider the magnocellular pathway's impact on math. Research by Boets et al. (2011) and Sigmundsson et al. (2010) has suggested that children with a disability in math may have an impairment in the magnocellular pathway.

Direct Retrieval

Direct retrieval of arithmetic facts is solved by what is stored in the child's memory-based processes. Memory-based processes may involve direct retrieval of basic math facts, decomposition, and the use of fingers (Geary, 2001). Simple addition problems can be solved by direct retrieval or a combination of direct retrieval and decomposition strategies (Geary & Wiley, 1991). Decomposition strategies involve the child applying a known fact to solve the answer to a math problem (e.g., 5 + 7 = 5 + 5 + 2). As typically developing children grow older and mature, they learn a set of basic math facts. These facts can be used to solve other facts that are a little more complex. Geary and Wiley

(1991) stated: “Even among adults, simple addition problems are not all solved using direct retrieval; generally, they are solved using a combination of direct retrieval and decomposition strategies” (p. 216). Pellegrino, et al. (1987) point out that from preschool through the fourth grade, children will learn basic facts that can be easily retrieved, and at the same time will be confronted with some facts that will need to be calculated. They go on to state that from the fourth grade through adulthood the typically developing child will solve simple math problems by retrieval from their memory rather than calculation. This process continues the building of facts which in turn, increases the speed of retrieval and therefore increases math fluency. Children with math disabilities often have problems with direct retrieval of basic math facts and lack math fluency (Whitehurst, 2003).

Children with disabilities in math make more errors than typically developing peers when asked to perform complex arithmetic problems. These children do not appear to make the transition from procedural-based problem solving to a memory-based problem solving that is found among typically developing children (Geary, Widaman, Little, & Cormier, 1987). Geary (1993) stated that problems with direct retrieval from the long-term memory can be considered a defining feature of dyscalculia math disability. Geary believes the mathematics is complex and that it is difficult to pinpoint a single learning disability in mathematics. Geary (2004) states:

> “… the complexity of mathematics makes the search for any associated learning disabilities daunting… competencies in any given area of mathematics will depend on a conceptual understanding of the domain and procedural knowledge that supports actual problem solving” (p.8).

Children with math disabilities are able to retrieve some facts from the long-term memory. Many children with math disabilities may retrieve facts with one operation (e.g., addition), but may have difficulty retrieving facts from another (e.g., multiplication). Therefore, difficulty with fast retrieval of arithmetic facts can be from a deficit in the speed of processing information and with the retrieval of knowledge from long-term memory (Bull & Johnston, 1997).

As children begin learning how to add and subtract whole numbers, they start to become fluent in simple addition and subtraction. Rapid recall of basic math facts is referred to as math fluency and is important for children to grasp higher-order skills in mathematics (Whitehurst, 2003).

Math Fluency

Fluency involves the ability to respond both accurately and quickly to a selected stimulus (Axtell, McCallum, Bell, & Poncy, 2009). In mathematics, children need to learn the basic facts to the level that they are automatically recalled. Automaticity implies that a skill can be carried out with minimal awareness of its use (Hartnedy, Mozzoni, & Fahoum, 2006). When children can automatically respond to a basic math fact, they have more cognitive resources that can be used to solve more complex calculations. The working memory has limited space for only a few calculations at any given moment. When the working memory is full with math facts, it has no room for math calculation. A study by Delazer, Domahs, Bartha, Brenneis, Locky, and Trieb (2004) using magnetic resonance imaging (MRI), showed an actual shift in brain patterns as math facts were learned.

One of the basic principles set by the National Council of Teachers of Mathematics (NCTM) is computational fluency. Skills in computation are characterized by the accuracy and speed in which an individual can solve a simple arithmetic problem. The accuracy and speed needed to solve a simple problem is referred to as fluency in math. For an individual to be fluent in math, he/she has to rely on the ability to retrieve previously learned basic math facts from the memory (Mabbott & Bisanz, 2008).

Basic math facts are the foundation to the more advanced knowledge of mathematics. If a student is solving a multistep problem and has automaticity in the first step, the student should be able to resolve the problem faster, and require less mental exertion. Students who are fluent in math score higher on achievement tests, show higher maintenance levels of learned skills over time, and show lower levels of math anxiety (Poncy, 2009).

Processing Speed

Visual processing speed is complex and involves more than just the speed with which one can process routine information (reaction time). Processing speed has somewhat of a reciprocal relationship with the working memory, in that an increase in processing speed can decrease the burden placed on working memory, while a reduction in processing speed can hinder the effectiveness of the working memory (Weiss et al., 2006). Kyllonen and Christal (1990), found that an interrelationship exists between working memory and processing speed. There is a significant amount of evidence in support of working memory and processing speed as major components of one's intelligence (Weiss et al., 2006; Jonides, Lacey, & Nee, 2005; Demaree, Frazier, Thomas, & Johnson, 2008).

For children to be fluent in math, they must be able to retrieve math facts from their memory in a fast manner. The speed at which the child can process easy and routine information without making errors is called visual processing speed (Wechsler, 2003; Weiss, Saklofske, Prifitera, & Holdnack, 2006). While this is a basic understanding of processing speed, it is a highly complex cognitive ability. Sandhu (2001) provides a more complex definition of visual processing speed ability. He defines visual processing speed as the ability to focus attention, quickly scan, discriminate between, and sequentially order visual information. Based on these definitions of visual processing speed, one can conclude that this capability is a core component of our everyday cognitive functioning. The rapid processing of mundane data involves ones' motivation and visual motor coordination, occurring from early infancy to geriatric ages (Salthouse, 1996; Dougherty & Haith, 1997).

Salthouse (1996) offers a model explaining how an impairment in one's processing speed can severely impact other cognitive skills in complex situations. He argued that if one is presented with a complex problem, tasks that would be completed at later steps may not be completed, because steps earlier in the problem could not be completed in the given amount of time. While processing speed may appear in very simple tasks requiring little mental energy, such as an adult writing a check, or a child putting a heading on a paper, processing speed tasks are, in fact, complex tasks, and require significant mental energy.

Research in the developmental process has further endorsed one's ability to quickly process routine information as an important factor in cognition. The work of Dougherty and Haith (1997) revealed that studies of an infant's processing speed were used to predict the infant's later IQ scores. Salthouse's (1996) study on cognition and aging revealed that the decline in general mental ability with age was due to a slowing of the mental processing speed. This research further supports the notion that the speed of processing information is strongly related to cognition. Based on studies of Salthouse (1996) and Dougherty and Haith (1997), findings indicate that there can be observed age-related trends in processing speed that are accompanied by age-related changes in the number of connections to the central nervous system.

This study used the two subtests, Coding and Symbol Search, of the Wechsler Intelligence Scale for Children (WISC IV) to assess processing speed. These two subtests may appear as easy, clerical functions and may seem like simple clerical functions, when in fact they are highly related to intelligence. Further, Deary and Stough (1996) findings, based upon intelligence scores, revealed a (r =.20) or slightly higher correlation between simple and choice reaction time, whereas inspection time, the rate at which information is processed, had a correlation of about (r = .40) (Deary and Stough, 1996; Deary, 2001). The studies suggest that the speed at which one processes information is a significant component of intelligence. The research of Horn and Noll (1997) identified processing speed as an important domain of cognitive functioning. Research on the Processing Speed Index score on the Wechsler scales has been found to reflect the effects of normal aging processes (Donders, Tulsky, & Zhu, 2001). Martin and Bush (2008) found that PSI on the Wechsler products was an "…efficient and reliable measure of processing speed." p. 40.

Research on the Processing Speed Index on the WISC IV has revealed that PSI is very sensitive to epilepsy and other neurological disorders. Therefore, a weakness in simple visual scanning and tracking can result in a lack of time and energy for acquiring new material suggesting that processing speed interacts with other higher order cognitive functions and influences the general cognitive functioning and everyday learning (Weiss et al., 2006).

Bull and Johnson (1997) noted that many errors in computation and immature counting strategies are the result of a poor representation of math facts stored in long-term memory. Their research concluded that children with difficulties in arithmetic have problems retrieving basic math facts, because of a deficit in the speed of processing. This suggests that the speed at which one can process information, and one's short-term memory, work together. Kail and Hall (2001) conducted a study to analyze processing speed to working memory. Their results showed consistently that age-related changes in processing speed related to change in the working memory.

Studies by Kail (1997) and Ferguson and Bowey (2005) have shown that as age increases, so does ones' processing speed, which in turn enhances the working memory through an independent path. Ferguson and Bowery (2005) studied children, between 5 to 13 years old, to determine the role of global processing speed in mediating age and found an increase in the auditory memory. They found age – associated increases in processing speed predicted the availability of long-term memory and the availability of long-term auditory (phonological) representations. Kail and Hall (2001) conducted two studies on children between the ages of 8 to 12 years old. Each was given measures of processing speed and a reading span. They found that age-related changes in processing speed was consistently related to changes in working memory. Both of these studies findings support the relationship of processing speed to the working memory.

The research of Weiss et al. (2006) supports Bull and Johnson's (1997) conclusion that processing speed is a factor in mathematics. They found that performance data from children with reading and math disorders demonstrated a similarity between children with specific math disorders and specific reading problems on verbal comprehension subtests. Some differences were found among the Perceptual Reasoning subtests. The children with difficulties in math were generally slower in the processing speed domain. Fry and Hale (1996) found that typically developing children were able to process information in a faster manner and, therefore, had more working-memory space available to them. Their study revealed that a child with a deficit in processing speed is slow in the retrieval of basic facts from their memory. They will then have difficulty applying direct retrieval strategies, making the process of addition very slow and frustrating for them.

Working Memory

The function of the visuo-spatial working memory is to hold information about what we have just seen (Baddeley, 2000). Some elementary pre-math tasks that appear to be related to math achievement in children include counting rate (articulation) and the rapid naming of digits (Denckla & Rudel, 1976; Norton & Wolf, 1991). The rapid naming of digits is equivalent to the rapid naming of letters or words in reading. Gersten and Chard (2001) stated that number sense in math was the equivalent to phonemic awareness in reading. They reported that for a child to succeed in math, children must have an understanding of what numbers mean, and they must be able to conduct some form of mental mathematics. In order for one to do mental mathematics, one needs to call on their working memory. Working memory is important to the learning of math (Geary, 2004).

Zheng, Swanson, and Marcoulides (2011) study concluded that all components of working memory play a large role in predicting problem-solving accuracy. The working memory is used to store and manipulate information for short periods of time. Zheng, Swanson, and Marcoulides (2011) described the working memory as having two passive storage systems, one used for the storage of oral information and placed in the phonological loop, and the other used for storage of visual information, called the visual spatial sketchpad. When it comes to reading skills, Swanson and Jerman (2007) reported that children with weak reading skills demonstrated lower levels of working memory than the skilled readers. When compared with the achievements of skilled readers, the achievements of children with reading disabilities indicated that pervasive memory deficits in the executive system play a primary role in literacy growth (Swanson & Jerman, 2007).

When it comes to mathematics, Geary (2004) stated that the relationship between working memory and difficulties in mathematics were not totally understood. It is necessary to use the working memory to perform complex math calculations. However, memory impairments involving the retrieval of math facts from the long-term memory and the working memory are paramount to success in math. He found that children with math disabilities have some form of working memory deficit and stated that the working memory plays a crucial role in one's mathematical ability. His study found that Rapid Automatized Naming (RAN) of numbers was a good predictor of children's success in math in the primary grades, just as RAN of letters was a good predictor of the reading achievement in the primary grades. In addition, his research also indicated that visuo-spatial working memory was also predictive of early math and phonological span of early reading.

Coherent Motion

Cornelissen, Richardson, Mason, Fowler, and Stein (1994) report a significantly less sensitivity to motion in children with dyslexia. Their findings suggest that it is feasible that the slight reductions in luminance contrast sensitivity demonstrated by children with dyslexia may be a dysfunction of their M-pathway. In their study of 29 readers with dyslexia and 29 readers with no dyslexia, Cornelissen et al.(1994) found that in children with dyslexia CMTs were 3 – 4% higher than those of children with age-appropriate reading skills. These results suggest that the reduction in motion sensitivity (CMT) found in readers with dyslexia cannot be attributed to a lack of reading experience. This supports the notion that poor motion detection can be related to poor reading in children with dyslexia.

Cornelissen et al. (1994) referred to a study conducted by Hill and Lovegrove (1993) and Geiger and Lettvin (1987):

> "…dyslexics made more errors when they read a whole line of text as opposed to single words presented in isolation. Their results are qualitatively similar to those of Geiger and Lettvin (1987), and suggest that abnormal interactions between peripheral and foveal vision in some dyslexics may affect their reading." (p. 1240)

CMT is acquired by showing a group of small, moving random dots in which some portion of the dots move in one uniform direction while the rest move in a random fashion (Skottun and Skoyles, 2006). The percentage of coherently moving dots is varied in each trial. The perceptual performance is then measured and is the percent of dots required for the subject to comprehend a coherently upward moving field of dots (Britten, Shadlen, Newsome, & Movshon, 1992). Skottun and Skoyles (2006) concluded that the use of CMT to assess magnocellular sensitivity has some problems. Cornelissen et al. (1994) concluded that it is believable that the M pathway deficit can affect reading abilities in some readers with dyslexia. Cornelissen, et al. (1994) and Skottun and Skoyles (2006) agree that more research is needed in this area.

Neurological Similarities in Reading and Math

Berch and Mazzocco (2007) believe that children's difficulties with math are poorly understood. They use the term "difficulties" in place of "disabilities" because they believe it opened up the field to a wider group of children in need of special help. They estimated that approximately one-half to as many as two-thirds of the children with math difficulties (MD) also experienced reading difficulties (RD). Badian (1999), Jordan & Montani (1997), and Rourke, (1993) focused their research on differences found between children with MLD who are succeeding in reading and children with RD as well as difficulties in math to discover if a core deficit in language has a commonality in both reading and math. Berch and Mazzocco (2007) argue: "The distinction between MD only and MD/RD is potentially important because the two classifications may represent different types of math difficulties with different developmental trajectories and outcomes" (p. 108).

Current research provides the profiles of children with a math difficulties (MD) only to children who are RD only, to children with both MD and RD, and the final group is the children that are typically developing in both reading and math (Berch and Mazzocco, 2007). These profiles can be used to make comparisons of each group to draw similarities and differences in achievement to help clarify the nature of classifications.

Geary, Hamson, and Hoard (2000) studied number deficits of second grade children by dividing second grade children into three groups, children with MD only, with RD only, with both RD and MD and typically developing children. (These children were not identified for special education services and therefore were not classified as learning disabled or children with dyslexia or dyscalculia.) Their findings revealed that children in both MD groups performed worse than their peers in counting knowledge. In addition number combinations, both MD groups made more counting procedure and retrieval errors than the typically achieving and RD only children. Also, their studied revealed that children with MD/RD made more counting and retrieval errors than the children with MD only. Both MD groups relied on finger counting to problem solve whereas the typically developing children relied less on their fingers. On cognitive tasks, the typical developing group scored higher on digit span, a working memory cognitive task, than the MD/RD group with the MD group scoring the lowest. The study also revealed that children with MD only and with MD/RD performed similar on basic number tasks than the typical developing children. This study is significant because it found a large number of numerical, counting and basic arithmetic deficits in children with MD/RD. The children with MD only showed a large number of deficits and delays in arithmetical competencies. The study found that MD/RD, and the MD, children committed more procedural errors and had a tendency to use developmentally immature procedures more frequently than their normal age peers. Many children with MD/RD or MD do not show the shift from procedural-based problem solving to memory-based problem solving that is usually found with average developing children.

Landerl, Bevan, and Butterworth (2004) conducted a similar study to Geary et al. (2000). Their study consisted of groups of 8 and 9 year old children, one group with dyscalculia (MLD) only, one group of only children with dyslexia (RLD), another group of children with both dyscalculia and dyslexia (MLD/RLD), and a group of typically developing children. Their findings revealed that children with MLD, regardless of the presence of RLD, showed deficits in number processing. Their results indicated that the groups of MLD/RLD was slower and made more errors than the children with only MLD. Landerl et al. (2004) concluded that dyscalculia can be defined as: "a deficit in the representation or processing of specifically numerical information" (p. 121). This study reveals that dyscalculia is related to disabilities in numerical processing, and not from deficits in other cognitive abilities.

Jordan, Hanich, and Kaplan (2003) investigated the development of specific mathematical abilities of second and third grade children with MD only, MD/RD only, RD only, and typically developing children. They defined difficulties as less than the 35^{th} percentile on a standardized achievement test. They found that children with MD only had an advantage over the MD/RD group in problem solving but not in areas related to basic calculation. This is probably due to problem solving items requiring reading (solving math story problems and understanding mathematical concepts). Basic calculation requires fast retrieval of facts and estimation. Their study revealed that MD only children had consistent difficulties with calculation fluency. Both MD and the MD/RD groups performed poorly on items requiring a fast response to number combinations. Both the MD and MD/RD groups relied heavily on finger counting. It was noted that the MD group did finger count; their finger counting was more accurate than the finger counting in the MD/RD group.

Geary (1994) suggests that reading difficulties and number fact retrieval both stem from a deficit related to phonological processing. The Jordan et al. (2003) findings do not support Geary's (1994) statement. Jordan et al. (2003) found that children with RD only performed better on tasks requiring rapid fact retrieval than did children with MD, and those with MD/RD. Berch and Mazzocco (2007) stated that empirical research did not support phonological processing that Geary (1994) suggested. They stated that although reading skills may predict an individual's achievement in math, number sense is a stronger predictor for math ability. Berch et al. (2007) argued that, "reading difficulties seem to aggravate rather than cause math difficulties" (p. 117).

Berch and Mazzocco (2007) argue that children with MD only, and those with RD only, perform similarly on problem solving tasks. They reported that these children used different pathways to solve the same problem. According to their research, the children with RD only capitalized on their math abilities, while the children with MD only capitalized on their reading abilities.

There have been empirical studies suggesting that visual processing deficits in the M-pathway play a significant role in dyslexia. Research by Sigmundsson et al. (2010) and Boets et al. (2011) revealed that M-pathway deficits can negatively impact one's abilities in math.

Studies indicate that dyslexia results in difficulties with the processing of letters and words from a written passage (Lovegrove, Bowling, Badcock, & Blackwood, 1980; Livingstone, Rosen, Drislane, & Galaburda, 1980; Stein & Walsh, 1997). Findings indicated that an impairment in the M-pathway leads to deficiencies in the visual processing of information. Reading disabilities are proven to stem from the visual system. The works of Stein (2001) and Talcott, Hansen, Assoku, and Stein (2000) demonstrated the importance of the relationship between dyslexia and deficits in the visual system.

Stein and Walsh (1997) address the fact that children's problems with phonology in reading do not explain the many other problems in reading that some children possess. Children with reading disabilities often transpose letters, produce incorrect phonological guesses for unfamiliar words, and according to Stein and Walsh (1997), this often may stem from visual confusion. Stein and Walsh, 1997) state that their MRIs have shown the planum temporale cortical language area is symmetrical or even larger on the right than the left side of the brain in people with reading disabilities. In average readers, the left hemisphere is normally larger. He uses this evidence to state that a specific reading disability is part of a congenital neurological abnormality, and defines this as, "the neurological term 'developmental dyslexia' is a more appropriate description" (p.148). Habib (2000) has found evidence that that dyslexia is a multi-system deficit which may be due to the brain lacking ability to perform tasks which require it to process brief stimuli in a rapid temporal succession. This may account for some of the perceptual, motor, and cognitive symptoms connected to a learning disorder. The work of Stein and Walsh (1997) and Habib (2000) point to dyslexia as having a neurological connection.

Neurological studies can show how the brain processes both, auditory and visual information. Studies conducted on the brain have demonstrated that abnormalities in both cerebral hemispheres can lead to learning concerns (Habib, 2000). Stein and Walsh, (1997) suggest that impairment in the magnocellular pathway may be part of a general developmental neuropathology which may affect the sensory processing in the rapid magnocellular pathway of not only the visual system, but the auditory and sensorimotor systems as well.

Neurological Component in Mathematics

It is interesting to note that some species of animals have demonstrated the ability to process quantities (Nieder, Freedman, & Miller, 2002). KoKo the gorilla is well known for her ability to use sign language and problem solve. Lipton and Spelke (2003) found that basic numerical knowledge can be seen in children during the infancy period. These young children were capable of processing quantities. They can distinguish quantity at less than one year of age. The research by Nieder et al., and Lipton and Spelke (2003) support the studies also conducted by Dehaene (2001).

Dehaene (2001) concluded that human mathematical abilities are biologically based. Dehaene and Cohen's (1995) research indicated that inaccurate retrieval of basic math facts is correlated to:

> "Whitaker, Habiger, and Ivers (1985), Corbett, McCusker, and Davidson (1988), and Hittmair-Delazer, Sememza, and Denes (1994) have each described a case of acalculia, including an inability to perform simple multiplications, following a left subcortical lesion in the basal ganglia. Both arithmetic facts and calculation procedures were impaired, although to a variable extent. Interestingly, Hittmair-Delazer et al.'s (1994) patient could still use conceptually elaborate strategies in order to sidestep his fact retrieval deficit. This indicates intact conceptual and operation sequencing resources. We therefore speculate that the circuitry of the basal ganglia is involved in the storage and retrieval of rote arithmetic memories and routing procedures, together with other routine "motor habits" (p. 105)

This finding supports other studies, which indicate that learning disabilities have a neurological basis. Orton (1925) believed that a reading disability was due to the brain's inability to associate the visual word with the spoken word. Numerous studies concerning the causation of learning disabilities have all indicated a neurological basis (Geary, 1993; Cornelissen, Richardson, Mason, Fowler & Stein, 1995; Sigmundsson, Anholt & Talcott, 2010; Boets, DeSmedt & Ghesuiere, 2011).

Simos, Kanatsouli, Fletcher, Sarkari, Juranck, Cirino, Passaro, and Papanicolaou (2008) conducted magnet resonance imaging (MRI) to study the inferior and superior right-hemisphere parietal regions of students with disabilities in math when performing simple arithmetic calculations. They found that the inferior and superior right hemisphere was more activated in students with disabilities in math. According to the researchers, this suggests that a network of the right hemisphere parietal, and possibly frontal areas, are involved in simple math calculations. The frontal lobe is more associated with reasoning, planning, problem-solving, and parts of speech. The right hemisphere is associated with multi-sensory input; memory is stored in auditory, visual, and spatial modalities.

Munro (2003) discussed how impairment in the processing of information in arithmetic can lead to various performance patterns. According to Munro (2003), children may differ in how they understand numerical information as opposed to how they may express information in numerical form. Students may process numbers in written numerals instead of in words. Students may understand individual digits but not their place value. Some students may use the verbal/auditory mode rather than written/visual mode to express their mathematical knowledge. Some students may correctly recall number facts but have difficulty in "calculation procedures." Other students may have difficulty recalling basic math facts or have difficulty doing simple arithmetic computations. The working memory plays an important part in the retrieval of basic math facts.

The Magnocellular Theory

The visual system can be characterized by two district parallel information processing functional streams called the magnocellular and parvocellular pathways (previously referred to as transient and sustained pathways based on a functional not strictly anatomical classification). These pathways are named for the relative size of the retinal ganglion cells that begin the neurological pathway from retina to brain. Magnocellular ganglion cells are larger in size and more densely distributed in the periphery of the eye. The magnocellular and parvocellular pathways largely remain segregated and independent of each other. Each has its own specific function necessary for vision (Thompson, Shillcock, & McDonald, 2003). The magnocellular and parvocellular project to different regions of the brain. Each pathway also transmits different types of visual information. The magnocellular pathway (M-pathway) processes information concerning object movement. The

M-pathway is monochromatic, i.e. does not process color information but is finely tuned to brightness contrast between object and background. The parvocellular pathway transmits highly detailed information needed for visual acuity and color. A magnocellular deficit has been found in certain types of dyslexia (e.g., Stein & Walsh, 1997).

Learning how to read is a complex process that involves both physiology, as well as cognition. Disabilities in reading then must involve physiology and cognition concerns. One explanation of a reading disability involves the aforementioned visual processing pathways. The magnocellular theory of reading disability suggests that the decreased performance of the M-pathway leads to a disruption in the normal sequential processing of visual information required for efficient reading. Stein and Walsh (1997) built the magnocellular theory on solid foundation by resting it on the findings of Cornelissen, Richardson, Mason, Fowler, and Stein (1994) and Galaburda and Livingstone (1993). Because the M-pathway responds with more sensitivity to moving objects than the more static P-pathway, motion sensitivity is thought to be a direct measure of M-pathway function. The Cornelissen et al. (1994) findings of impaired visual motion sensitivity to high contrast and illumination levels have been confirmed by magnetic resonance imaging (MRI). Galaburda and Livingstone (1993) findings included five brains of people with dyslexia, which were examined post mortem. Galaburda et al. (1993) found that magnocellular cells were more than 20 percent smaller in the dyslexic brains than in the control brains, and the brains were overall disordered. Based on these results, Stein and Walsh (1997) concluded that readers with dyslexia have a basic impairment in their visual processing systems. The basic impairment in the visual system is found in the magnocellular pathway.

The magnocellular cells (M-cells) specialize in movement, depth and small differences in brightness. They have a large center-surround receptive fields which are highly sensitive to depth, and indifferent to color. The M-pathway information is received in the visual cortex faster (7 to 10 milliseconds) than the parvocellar stream (P-stream) (Maunsell & Gibson, 1992). This allows the visual system to localize an object first and then identify it. The M-cells rapidly adapt to a stimulus. The M-pathway provides information about where an object is located in space. There is a correlation between the strength and speed of a response and the contrast between the stimulus and the background; the greater the stimulus contrast, the stronger and faster M-pathway response. The M-pathway also is responsible for motion. The M-pathway's responsibilities are to provide a way for localizing objects in space, determine the shape of objects, and their direction of movement (Snowden, Thompson, & Troscianko, 2006).

Parvocellular cells (P-cells) specialize in color (red/green), fine details (for visual acuity), orientation, texture, shape, and high spatial frequency. The P-cells are smaller than the M-cells. The P-stream is weak at processing rapidly moving targets when compared to the M-pathway (Snowden et al., 2006).

Snowden et al. (2006) describe the visual process beginning at the cornea, which is in front of the eye. The light travels through the cornea to the retina, which is in the back of the eye. The fovea is located in the center of the macula region of the retina and is responsible for clear vision. When light strikes the rod and cone photoreceptors their electrical signal is transmitted to retinal ganglion cells, divided into magnocellular and parvocellular (also the smaller and less numerous konio) cells. The M-cells are large and located more frequently away from central vision, while the P-cells are located in the fovea and are smaller cells. The optic nerve sends the information to the lateral geniculate nucleus (LGN). The LGN is part of the central nervous system and is responsible for the processing of all the visual information that is received from the retina. The LGN is located in the thalamus section of the brain. The LGN is layered (similar to a multi-layered cake). The first two inner layers are the M-pathway, and the outer four layers are the parvocellular pathways. The information is then taken to the brain for processing. This is known as visual processing (Snowden et al., 2006).

Both the M-pathway and P-stream play a significant role in reading. Each one is specialized for transmitting different visual information to the brain for processing (Snowden et al., 2006). The model suggests that the P-pathway allows the reader to see the text clearly, while the M-pathway is involved in the control of saccadic eye movements required to move the eyes through the text. The M-pathway is also thought to be involved in the shifting of visual attention across the line of text. Abnormalities in the M-pathway have been identified in the human brain of individuals with reading disabilities. Anatomy of the human brain has shown cell layers one and two of the lateral geniculate nucleus of the brain of reading disabled were smaller than those in a typically developing reader (Livingston, Rosen, Drislane, & Galaburda, 1991).

An M-cell deficit can be found in many forms of dyslexia. Readers with dyslexia tend to have different eye movement patterns compared to the control participants (Thompson et al., 2003). They also have difficulty in maintaining stable eye fixations as well as have difficulty with convergent eye movements (Thompson et al., 2003.) The visual M-cell system is responsible for timing visual events when reading (Stein & Walsh, 1997). Many people believe that during reading the eyes move continuously along a line of text, but instead the eyes make short, rapid eye movements called saccades intermingled with short stops called fixations. During each fixation, visual input occurs. The M-pathway signals any visual motion that occurs. Therefore, for a typical reader, as reading skills improve their number of fixations decrease, the number of regressions is fewer, and saccades are longer. Because magnocellular pathway helps to recognize the size and shape of the word, the reader does not have to stop and fixate on each word to process it. The P-path is responsible for fine detail and color (Snowden et al., 2006).

An important contribution of the M-cell system is the control of eye movements. Impairment in the magnocellular system can have a negative effect on the binocular fixation (ability for both eyes to converge on a letter or word). When this occurs the child may experience visual confusion, letters may seem to move around on the page. Hence, they can make many visual errors during reading (Stein & Walsh, 1997). It is important to note that at least one research group suggest that the M-cell theory can be generalized to the auditory, and tactile senses as well (Ramus et al., 2003). Ramus et al. states that the magnocellular theory (or large neuronal cells) can account for all symptoms of dyslexia (visual, auditory, tactile and phonological).

Professor Joel Talcott, Professor of Developmental Cognitive Neuroscience, has done a considerable amount of research on the M-path's impact on reading ability (Stein & Talcott, 1999; Talcott et al., 2000; Talcott, 2002). Stein and Talcott's (1999) work in connecting the role of visual processing to the reading process has brought new light on the cause of dyslexia. Reading was thought to be predominantly a phonological process. The work of Stein and Talcott (1999) has proven that it can be a visual processing deficit, as well. Visuo-spatial processing skills have been found in children with Williams' syndrome (O'Hearn & Luna, 2009). These visuo-spatial skills will impact one's ability to perform in geometry but not in basic arithmetic. The impact of the M-path on math has only recently been explored.

Sigmundsson, Anholt, and Talcott (2010) noticed that developmental learning disabilities are highly comorbid with deficits in both reading and math achievement. Their research suggested a range between 20% to 60% of co-occurrence. This high rate inferred that they share some common underlying trait connecting both. They developed a research study to investigate if a deficit in visual temporal processing, as “indexed by sensitivity to coherent motion,” was present in children with impaired mathematic skills, as it is evident among dyslexic readers. They predicted that dyscalculia would be linked with reductions in sensitivity to coherent motion. Their results showed that children weak in math skills were significantly less sensitive to coherent motion than the control group of children strong in math. This suggests that the M-pathway impacts some aspects of math ability, as well as reading ability.

Sigmundsson, et al. (2010) suggests that the M-pathway affects not only reading ability but also has an impact on math ability. Sigmundsson et al. (2010), and Boets, DeSmedt, and Ghesquiere (2011) researched to determine whether visual dorsal stream functioning could be a predictor of individual differences of specific mathematical skills. They investigated whether coherent motion sensitivity was associated with subtraction (single digit) and multiplication (single digit) performance. The results indicated that a connection between subtraction existed, but that no connection was found with multiplication. They concluded that the findings indicated that coherent motion sensitivity may predict later performance in mathematics.

Coherent motion detection is the best measure to detect motion sensitivity of the M-pathway. Boets, Vandermosten, Cornelissen, Wouters and Ghesquiere (2011) found that individuals with dyslexia have shown significantly elevated coherent motion thresholds (CMT) in 20 out of 26 studies. They go on to state that CMTs have been connected to letter positioning encoding, reading ability, and orthographic ability. They also point out that there are other factors that impact reading ability. They state that visual word recognition, visual attention, letter position encoding, and binocular stability have all been found to be impaired. There is evidence that also demonstrates that reduced visual motion sensitivity in dyslexia is not unequivocal because a number of studies have been unable to replicate the same findings mentioned above (Amitay et al., 2002; Hutzler et al., 2006; Kim & Davis, 2004). In a study conducted by Cornelissen, Richardson, Mason, Fowler, and Stein (1995) dyslexic children's CMT was 3 to 4% higher than the nondisabled reading child. Therefore CMT detection can act as a good detection between the dyslexic reader and the average reader. Cornelissen et al. (1995) make a note of caution stating that although the study found it harder for the dyslexic to detect coherent motion than the average reader. This could be a sign of generalized dysfunction in the parietal visual pathway and not a failure of the M-pathway. They suggest the need for further research and more studies to replicate their findings. Their study specifically used coherent motion in random-dot kinematograms to determine if dyslexics have an impaired M pathway. Coherent motion sensitivity is a reliable way to measure magnocellular processing (Milne et al., 2002).

Coherent motion sensitivity can be measured by random-dot kinematograms. Random-dot kinematograms consists of a series of patterns of random dots that are shown in a fast (millisecond) succession. The proportion of dots is systematically changed to new positions which present the visual system with a temporal correspondence problem (Cornlissen et al., 1995). The presented problem is a certain percentage of dots move in one direction that is coherent over time, while the remaining dots randomly change their direction of motion over time. Motion coherent threshold is measured by calculating the lowest percentage of dots needed to move coherently for the participant to correctly determine the direction of coherent motion.

There is a subtle relationship between visual word recognition skills, contextual reading and in one's ability to detect coherent motion in a random dot kinematorgram. Boden and Giaschi (2007) have identified several processes that depend on dorsal stream processing (as indexed by CM sensitivity) and they feel are significant for reading fluency and strong visual word recognition. Boden and Giaschi (2007) strongly feel that visual attention (Vigyasagar, 2004), letter position encoding (Corrnelissen, Hansen, Gilchrist, Cormack, Essex, & Frankish 1998), binocular stability (Stein and Fowler, 1993) and oculomotor control (Pavlidis, 1981) all play a role in the reading process.

Summary

Every child must develop certain basic skills in their early stages of development if they are to become proficient in mathematics. These skills are often referred to as number sense, counting, and number comprehension. As children enter school they begin to develop a deeper understanding of the concepts of arithmetic and begin to compute simple addition problems. They usually begin by using their fingers to count. Many children finger count while some may rely on verbally counting out the addends without using their fingers. Simple subtraction follows and is similar to the process of learning addition. Geary et al. (2001) found that both procedural and memory-based deficits were common among children with developmental dyscalculia.

As typically developing children grow older they learn basic math facts. These basic facts are used to solve more complex problems. As they continue to learn facts, they develop faster speeds of retrieval of these facts which increases their math fluency. These are memory based processes and involve the direct retrieval of basic math facts (Geary, 2001). Children with disabilities in math often have difficulty with the direct retrieval of math facts. Geary (1993) feels that problems with direct retrieval from the long-term memory are a defining feature of dyscalculia.

As children grow older the average learner develops faster recall of the basic math facts, this in turn allows them more cognitive resources that they can use to solve more complex calculations. This is referred to as math fluency (Axtell, McCallum, Bell, & Poncy, 2009). Math calculations occur in the working memory. The working memory has very limited space; fast retrieval of basic facts can free up space within the working memory. Faster processing speed can positively impact the working memory by allowing for faster recall of the basic math facts.

Processing speed has a reciprocal relationship with the working memory because an increase in processing speed can decrease the burden placed on the working memory. There is a significant amount of evidence in support of working memory and processing speed as components of a person's cognitive functioning (Weiss et al., 2006; Jonides, Lacey, & Nee, 2005; DeLuca & Kalmar, 2007). The work of Dougherty and Haith (1997) found that studies of an infant's processing speed could be used to predict the infant's later IQ scores. Dougherty and Haith's (1997) findings suggests that there can be age-related trends in processing speed that are accompanied by age-related changes in the number of connections to the central nervous system.

Working memory is used to hold and manipulate information for short periods of time. The relationship between the working memory and math difficulties are ambiguous, and memory impairments involving the retrieval of math facts from the long-term memory and the working memory are a hindrance to success in math (Geary, 2004). Geary (2004) concludes children with a disability in math have some form of deficit in the working memory. Therefore, the working memory is crucial to success in math.

Cornelissen, Richardson, Mason, Fowler, & Stein (1995) found that children with dyslexia had significantly less coherent motion than the average child. This suggests that there may be a slight impairment of the M-pathway. Coherent motion threshold is acquired by showing small, moving random dots in which some of the dots move in a vertical direction while the remaining dots move in a random manner. Reading disabilities are proven to stem from the visual system. The works of Stein (2001) and Talcott, Hansen, Assoku, and Stein (2000) demonstrated the importance of the relationship between dyslexia and deficits in the visual system.

The Dehaene and Cohen's (1995) study indicated that the retrieval of basic math facts is correlated to the basal ganglia, thalamus and the left parieto-occipito– temporal areas in the brain. Simos, Kanatsouli, Fletcher, Sarkari, Juranck, Cirino, Passaro, and Papanicolaou (2008) found, through the use of MRI studies, that the inferior and superior right hemisphere were more activated in students with disabilities in math.

Cornelissen, Richardson, Mason, Fowler, and Stein (1995) found that an impaired M-Pathway may impact a child's ability to read. Sigmundsson, Anholt, and Talcott, (2010) found the M – pathway can impact one's ability in mathematics. The magnocellular pathway processes information concerning object movement. Abnormalities in the M – pathway have been located in the human brain (Livingstone, Rosen, Drislane, & Galaburda, 1991).

Chapter 3

Methodology

This chapter outlines the methodology that has been used for the study. It includes a review of the research questions that were addressed, and a description of the study, its design, participants, instruments, and procedures.

Design

This quantitative study investigated the relationship of Processing Speed Index (PSI) and coherent motion sensitivity on math ability of children in two different groups. Originally the study tried for one group of students to include children with a diagnosed learning disability in math only. However, it was very difficult to find students with a learning disability in math only. Only four students were found for the study. Therefore, there were only two groups of students. Group One was comprised of students with a learning disability in math only, and children with a diagnosed learning disability in both math and reading. Group Two was comprised of typically-developing children who had no record of diagnosed disabilities. The study attempted to determine if a relationship existed between a child's M-pathway (as determined by CMT), and his/her processing speed. Processing speed was measured using the Processing Speed Index (PSI) on the Wechsler Intelligence Scale for Children, 4th edition (WISC-IV). The results were compared to each subject's sensitivity to coherent motion using random-dot patterns to determine a CMT. Children in each group were compared to children in the other group on both measures of PSI and CMT. It was anticipated that children who have been diagnosed with a learning disability in math only, or in both math and reading, (i.e., Group 1), would demonstrate a higher CMT, and would score lower on math fluency and math calculation, when compared to typically developing children (Group3).

The following three (3) research questions that were addressed in the study:

Is there an inverse relationship between PSI and CMT?

Is a score on PSI associated with a child's performance on math fluency and math calculation?

Is CMT associated with PSI or math fluency and math calculation?

Based on these research questions, the following hypotheses were tested:

- Hypothesis #1: There is an inverse relationship between PSI and CMT
- Hypothesis # 2: There is a positive relationship between a PSI score and the scores on measures of math fluency and math calculation.
- Hypothesis #3: When a low PSI score is combined with high CMT a positive relationship will result with scores on measures of math fluency and math calculation.

A quantitative study was used to analyze the relationship between CMT and PSI. It was hypothesized that there is an inverse relationship between PSI and CMT. A correlational analysis along with a linear regression model was conducted to gather data relative to Hypothesis One. It was further hypothesized that PSI is associated with a child's score on math fluency and math calculation, and that CMT is associated with PSI on math fluency and math calculation. A regression analysis was conducted to gather data relative to Hypotheses Two and Three.

Each child was tested with the WISC-IV subtests: Coding and Symbol Search, the Woodcock Johnson Tests of Achievement, Edition III (WJIII) subtests for Math Fluency and Math Calculation. Each child was assessed for sensitivity to coherent motion by assessing their CMT using the Psykinematix software program. The results obtained from each child on those subtests were analyzed to determine if a child with a deficit in math fluency and math calculation also had deficits in the PSI. Results were also analyzed to determine if children with a low PSI score were deficient in math calculation, and have a high CMT. This would indicate that a deficit in the M-pathway may be correlated to low performance in mathematics.

Participants

A total of 33 (2rd through 8th grade) children from four public school districts and one private school in a Midwestern suburb were identified to participate in the study. All subjects in the study were matched as closely as possible to categories of average IQ scores and ages. Two of the school districts selected for the study were suburban districts with enrollments of approximately 5000-6000 students, one district was a large urban district located within the city limits and one district was located in a more rural area outside of a major city. Students from one private Catholic school were also used in the study.

Table 1 displays the demographics of children in each school district. Information on each district was obtained from 2014 data from Proximity One. Information on each school was obtained from the school principal.

Table 1

Demographics of each district used in the study

District/School	**Total population**	**# Elem. schools**	**# Middle Schools**	**% Caucasian**	**% African American**	**Other**	**# Students in the study**
A	5,182	5	2	74.8	17.1	8.1	3
B	6,112	8	1	90.8	5.4	3.8	9
C	6,117	6	2	69.7	24.6	5.7	8
D	27,212	49	9	44.5	48.9	6.6	4
E	180	1 K - 8	0	97.5	2	.5	9

The chart illustrates the school districts of students who participated in the study. The students participating in the study came from schools with diverse populations. Districts A, B, C, and D were public schools. All of the districts and the private school were located in and around a Midwestern city. District D was an urban school district located in the heart of a city, and district C was more rural, and located on the outskirts of a city. School E was a private Catholic school (not a public school district).

The diagnostic status groups were comprised of three groups. The first of the three groups was comprised of children with a learning disability in math only. The second group of children had a learning disability in reading and in math, and the third group was made up of typically developing children with no diagnosed disabilities. The group of typically developing students served as the control group, and the remaining two groups served as the experimental groups. A total of 33 participants were tested in all. The following criteria were used to select each group of students:

- Group 1 (experimental) was comprised of twelve (9 males and 7 females) students identified as having a specific learning disability. Four students (3 males and 1 female) had a learning disability in math only. Six males, and six females had a learning disability in both math and reading. All students were receiving special education services. Diagnostic identification abides by the school district's procedures and state guidelines for a SLD in math and reading, using the discrepancy model. A reading deficit is based upon a psycho-educational evaluation with achievement scores in one or all of the following areas: basic reading skills, reading fluency or reading comprehension, that demonstrate one and one-half standard deviation from their potential (IQ).
- Group 2 (control) was comprised of sixteen typically developing students (7 males, and 9 females) with no categorical diagnosis; none had been retained, nor had ever received special

education services. They demonstrated scores at the Proficient or above level in math on the state assessment.

Participants for the study were obtained from four public schools in districts within a metropolitan area and one private parochial school. Participants in the study consisted of 2 students from eighth grade, 5 students from sixth grade, 13 students from fifth grade, 2 students from fourth grade, four from third grade, and 8 students from second grade (Table 2). Guidelines and steps that were followed in the identification and assessment of the subjects involved in the study are listed in Appendix A.

The Director of Special Education was contacted in each of the school districts that participated in the study. All participants who met the criteria were selected by the host district using the parameters for each group described above. The Special Education Director from each district participating in the study was given the parameters for students in each group. After permission from each district was granted, resource teachers within each district were contacted to identify potential participants who met the established criteria for each group. The teachers identified the students that met the parameters for the study and contacted the children's parents. Parent permission for students to participate in the study was obtained. A copy of the letter appears in Appendix C. Once parent permission was obtained, the researcher gave a letter explaining the project to each of the children asking for his or her permission to participate in the project. A copy of this letter appears in Appendix B. After the children gave their permission to participate in the study, testing began. Each student was given an eye exam using the Snellen chart which is used by school nurses to measure visual acuity.

The principal at the parochial school was contacted. The principal read the proposal and agreed to participate. She personally contacted each parent and obtained permission to test.

Data collection occurred over a 15 month period. The researcher went to each school, and met with the children to administer a visual acuity screening. Students passing the screening were then administered the math fluency and math calculation subtest, as well as the CMT and processing speed subtests. Testing for each child in groups 1 and 2 was completed within a 45-minute period. Testing for each child in group 3 was about 75 minutes. After testing was completed each child received a ten-dollar gift card for participating in the study. Results were sent home to parents explaining the results of the evaluation. (Appendix D)

Instruments and Procedures

Prior to any testing, all children in the study were given an informal vision screening, using the Snellen Eye Chart for visual acuity. Children with normal vision (20/20 both near and far point with or without correction) were included in the study. Children with less than 20/20 corrected visual acuity were excluded from the study. Only one child in the study wore eye glasses.

The following measures were used to assess each child in the study:

1. Coherent Motion Threshold (CMT): The Psykinematix software program was used to assess coherent motion.
2. Math Performance: The Math Fluency and Math Calculation subtests on the Woodcock Johnson III Achievement Battery were used to assess math abilities.
3 Processing Speed Index: The Coding and Symbol Search Subtests from the WISC IV were used to assess each child's processing speed.

In addition, all students in the group of typically developing children received the Kaufman Brief Intelligence Test (KBIT 2). KBIT2 results were used to eliminate any subject from the group of typically developing students whose IQ did not fall within the average range (90-109).

Table 2 illustrates the assessments that were administered to each group of children.

Table 2

Assessments to be administered to each group of children

Group	**Number of children in each group**	**Assessments administered**
Group 1: Children with a disability in math Children with a disability in math & reading	3 sixth gr. 1 fifth gr. 1 sixth gr. 7 fifth gr. 2 fourth gr. 2 third gr. 1 second gr.	Coherent Motion Threshold WISC IV: Processing Speed o Coding o Symbol Search Woodcock Johnson 3 Math Fluency and Calculation
Group 2 Typically developing children	 2 eighth gr. 1 sixth gr. 4 fifth gr. 2 third gr. 7 second gr.	Coherent Motion Threshold WISC IV: Processing Speed o Coding o Symbol Search Woodcock Johnson 3 Math Fluency and Calculation KBIT II

Coherent Motion Threshold

To detect sensitivity to coherent motion the Psykinematix program was used. Random-dot kinematograms accurately determine the detection of lateral coherent motion (Cornelissen et al., 1995) by measuring each child for his/her sensitivity to coherent motion (CMT) under low luminance conditions. Use of this instrument involves placing a laptop computer on a table that is positioned, such that the viewing distance of the screen is approximately 18 inches directly in front of each subject. CMT is determined by counting the total number of dots that appeared to move together in a single direction on the horizontal axis.

The subject observed the computer screen. A rectangular frame viewed on a high resolution LCD screen and display mode of 1280 pixels x 800 pixels with a 150 high luminance white dots was presented on a black background. Practice trials were conducted first to ensure that everything was working properly, that all parameters were correctly set, and that the participant understood what he/she was being asked to do while participating in the study. Once the participant was seated, he/she was closely monitored to prevent any body movement that may change the visual angle of the stimuli on the subject's retina. CMT is measured by calculating the lowest percentage of dots needed to move coherently for the participant to correctly determine the direction of the coherent motion.

Math Fluency

The Woodcock Johnson Tests of Achievement (WJ III) were selected because they measure many facets of academic achievement. Psychologists and examiners are permitted to select the subtests they need in order to assess an individual child's abilities. The WJ III was normed on 8,800 children and adults (4,700 students K – 12) in a thorough national sample (Willis, 2002). The achievement tests can be compared directly and in combination with cognitive assessments (WJ cognitive) to measure Cattell-Horn-Carroll (CHC) factors (Kaufman, 2009).

The Woodcock Johnson III (Woodcock, McGrew, & Mather, 2007) math fluency subtest was used to measure each child's math fluency. Math fluency on the Woodcock Johnson III is assessed using visual stimuli. The child was given 16 rows of basic math facts (addition, subtraction, and multiplication), with ten problems in each row. The child was asked to use a pencil, and to quickly and accurately solve as many problems as he/she could during a three-minute timeframe. Raw scores were transformed into standard scores based on each student's age. Raw scores were converted into standard scores which were used in analysis.

Math Calculation Skills

The Woodcock Johnson III (Woodcock, McGrew, & Mather, 2007) math calculation subtest was used to measure each child's math calculation ability. This subtest measures the ability to perform math calculations in addition, subtraction, multiplication, division, and combinations of these basic operations, as well as some geometric trigonometric, and logarithmic operations. There is no time limit on the test. The students are given a set of math problems and begin to solve problems at their grade level. They continue to solve each problem until they miss six consecutive items. Errors can be detected in regrouping, problems with zero, poor column alignment, lack of attention to signs, and basic algorithms.

Visual Processing Speed

The Coding and Symbol search subtests of the WISC IV were used to measure each participant’s visual processing speed. The Coding and Symbol Search Subtests result in a Processing Speed Index. The Processing Speed Index on the WISC IV was chosen because it is highly respected among the psychological community as being a valid measure of a child’s ability to process information quickly and accurately (Kaufman, 2009; Weiss & Gabel, 2008). Coding is a direct test of speed and accuracy which requires the child to quickly draw symbols that correspond to a specific number. The child sees the association key at the top of the paper and quickly tries to record as many symbols as possible, within a two-minute time period. Weiss, Saklofske, Prifitera, and Holdnack (2006) claimed that: “Children with poor visual discrimination skills may be slowed by the need to decode visual stimuli into their correct components” (p. 263). During a two-minute time period, Symbol Search requires a child to match visual symbols to determine if the symbol on the left of the paper does or does not match with the symbols on the right side of the paper. The child must respond to a visual representation using a written response of “yes” or “no.” Raw scores from both sets of data were converted into scaled scores, and then added together and converted into a standard score that represents a Processing Speed Index.

IQ Assessment

Students in the two experimental groups had an established diagnostic status (children with a SLD in math and the children with a SLD in both reading and math). These students had been administered an individual intelligence test by their respective district's psychological examiner according to the procedures put forth in the manual and state regulations as part of the diagnostic process. Each of these subjects had an IQ score on record and only those students with a score in the average range were considered for the study. Therefore, subjects in all three study groups had IQ scores in the average range (90-109) to ensure that IQ was not a variable in the study.

Students in the control group (Group 3) were individually administered the KBIT 2 to establish that these participants had IQ scores within the average range. The test includes two measures of verbal ability (i.e. Vocabulary and Riddles) that measure crystallized ability, and one subtest of nonverbal ability: Matrices, which measures fluid intelligence. The KBIT 2 does not include working memory or processing speed as part of the composite score.

Written procedures and guidelines that are provided in the test manual were followed on all testing completed with each child. The school psychologist conducting the KBIT testing for all Group 3 students in this study has over ten years of expertise in testing children in both cognitive and academic testing. A summary of the written guidelines used in the individual IQ testing are provided in Appendix A.

Validity and Reliability

Test validity refers to the extent that a test measures exactly what it purports to measure (Cohen & Swerdlik, 2004). Validity is not referred to as a statistic, but as a body of research proving that there is a strong and positive relationship between the test and what it is meant to measure.

Reliability refers to the ability for the test to consistently ascertain the same results (Cohen & Swerdlik, 2004). A test is reliable if the same results are obtained on repeated trials.

The Wechsler Intelligence Scale for Children (WISC-IV) Processing Speed Index consists of two subtests: Coding and Symbol Search. Internal consistency for reliability was administered using 243 children, using the test – retest model. The reliability coefficients for Processing Speed is .88 to Full Scale IQ is .97. The Coding subtest has a coefficient of .85; Symbol Search has a coefficient of .79.

The Kaufman Brief Intelligence Test 2 (KBIT 2) reviewed trends of subtest mean raw scores with age, and correlations with other similar tests for validity. The KBIT 2 was correlated with the Wechlser Abbreviated Scale of Intelligence (WASI). Results revealed a strong correlation between the two instruments. The KBIT 2 vocabulary score correlated highly with the WASI VIQ (r = .80) and vocabulary subtest (r = .80) for ages 7 – 19. The full scale IQ had a correlation of (r = .81). The relationship between the KBIT 2 and the WASI was very strong. Age differentiation revealed a steady increase in the mean raw scores on all tasks throughout childhood and adolescence, and changes from late adolescence through old age. Reliabilities for the Verbal scores range from r = .86 to r = .96 (mean = .91). Reliabilities for Nonverbal scores range from r = .78 to r = .93 (mean = r =.86). Reliabilities for the IQ Composite are strong, and range from r =.89 to r =.96, and average r =.93.

Data Analysis

The first research question for the study (RQ1) was: Is the Processing Speed Index (PSI) associated with a child's CMT? It was hypothesized that there is an inverse relationship between PSI and CMT. This hypothesis was investigated using a correlational analysis along with a linear regression model.

The second research question (RQ2) was: Is a score on PSI associated with a child's performance on math fluency and math calculation? It was hypothesized that PSI is associated with scores on measures of math fluency and math calculation. Hypothesis 2 was analyzed using a regression analysis.

The third research question (RQ3) was: Is PSI combined with CMT is associated with scores on measures of math fluency and math calculation? It was hypothesized that a score on PSI combined with CMT results is associated with scores on measures of math fluency and math calculation. Hypothesis 3 was analyzed using a regression analysis.

Table 3 provides a key to the abbreviations used in the statistical analyses.

Table 3
Key to abbreviations

PSI	Visual Processing Speed as measured by the Processing Speed Index on the WISC IV
CM	Sensitivity to coherent motion
WJIII	Math Fluency and Math Calculation as measured by the subtests on the Woodcock Johnson III
Group	Diagnostic status dummy coded as:
ds_m	Diagnostic status – children with math disability only
ds_{mr}	Diagnostic status – children with a reading and math disability
ds_{nd}	Diagnostic status – typically developing children with no disability

Prior to the analysis, normality was tested to ensure that all of the variables are uni- and multi-variate normal distributed. This was done by comparison of the central tendency (mean, medium and mode) and a frequency histogram. "Frequency histograms are an important graphical device for assessing normality, especially with the normal distribution as an overlay…" (Tabachnick & Fidell, 2007, p. 81). Collinearity was checked using both correlation and scatter plot matrices.

The Levene's Test of Homogeneity was used to assess the equality of variance among the three sets of data, while a Chi-Squared Test assisted in determining normality of the residuals. Significance was tested with the general F-test ration and the meaningfulness and usefulness of the models were indicated by the coefficient of determination (R^2). Dr. Starkweather (2010), a research and statistical support consultant, states that testing assumptions for analysis *is* a vital and necessary step in analysis. Dr. Starkweather (2010) states, "Generally, the Levene's Test is used to statistically test the amount of difference between variances (of groups selected for a *t*-test or *F* test) (p. 1).

Summary

The study consisted of 33 students in grades 2-8 from four different school districts and one private school in the metropolitan area. Students were placed into three different groups based on their SLD status. Group 1 included students with average IQ scores who had been diagnosed with a learning disability in math only. Group 2 included students with average IQ scores who had been diagnosed with learning disabilities in both reading and math. Group 3 included typically developing students with average IQ scores and no learning disability diagnoses.

Students in each group were administered a battery of tests including CMT, PSI, math fluency and math calculation. CMT was measured using random-dot kinematograms. PSI was measured using the WISC-IV subtests of Coding and Symbol Search. Math fluency was measured using the WJ-III Math Fluency and Math Calculation subtests. Students in Group 3 were also administered the KBIT-II to ensure that IQ scores for all students in this group were within the average range (90-109). IQ scores for students in Groups 1-2 had been previously administered at the time of diagnosis and all participants had scores within the average range (90-109).

Hypothesis 1 was tested using a simple correlational analysis to determine whether an inverse relationship exists between CMT and PSI. Hypothesis 2 was tested using an ANOVA to determine whether an association exists between low PSI and low scores on measures of math fluency and math calculation.

Hypothesis 3 was tested using an ANOVA to determine whether an association exists between low PSI combined with high CMT and low scores on measures of math fluency and math calculation. Chapter Four provides an analysis of the data. The findings from the statistical analysis of the data are presented and analyzed.

Chapter 4

Results

This chapter presents the results of the study designed to determine the impact of visual processing and coherent motion on math skills for three groups of children. Group 1 includes children with a learning disability in math only, Group 2 includes children with a learning disability in both math and reading, and Group 3 is comprised of typically developing children. The results were used to determine if there is a relationship between a child's neurological functioning, as measured by PSI and coherent motion, and his/her academic performance in mathematics on measures of math fluency and calculation.

Overview of Methodology and Design

A total of 33 students from 4 school districts and one private school within a Midwestern state agreed to participate in the study. The 33 students were divided into 2 groups. Only four students in the study were identified as having a learning disability in math only. Thirteen students were identified as having a disability in both math and reading. All of the children with a learning disability in the study comprised Group 1 for the study. Sixteen students were typically developing children with average IQ scores (90-109 as measured by the KBIT II), no learning disability diagnoses, and no history of grade retention. While 33 students meet a statistical threshold for a statistically significant sample size, larger groups would add more significance to the results of the study.

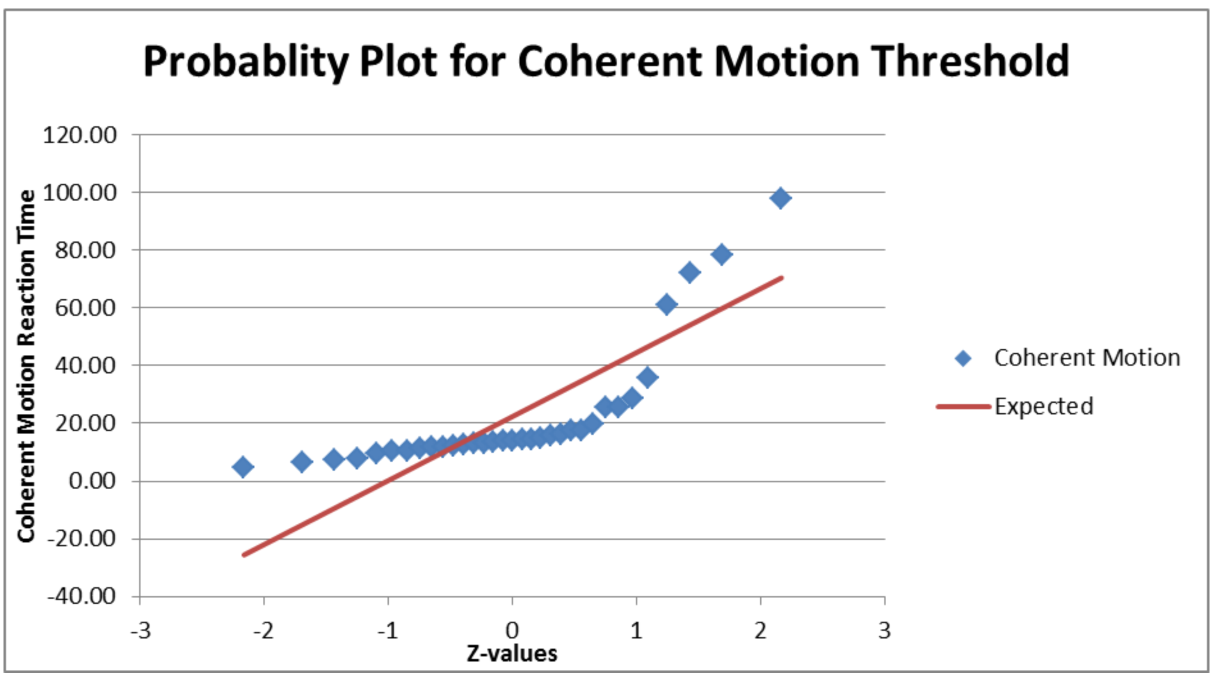
All data were compiled on an Excel Spreadsheet (Appendix F). A sample mean and sample standard deviation was determined for each category (Coherent Motion, Processing Speed, Math Calculation, and Math Fluency). Z -scores were determined to identify any outliers that were three standard deviations away from the mean. One outlier was identified within the Coherent Motion data. The subject was 3.4 standard deviations above the mean of 22.43 CMT. This student's data was removed from the sample, leaving 32 students' data in the study, and twelve students in group two.

Tests for Normality of Data

The Levene's Test of Homogeneity was conducted among the four categories (Coherent Motion, Processing Speed, Math Calculation, and Math Fluency) and indicated no statistically significant difference in variance among the three groups (Math, Math and Reading, and Typically Developing Students).

A frequency distribution was conducted to determine the pattern of distribution of the data. A Normal Probability Plot was used on all categories to further test for normality. Coherent Motion plots did not form a line, which suggested a departure from normality (see Graph 1.1).

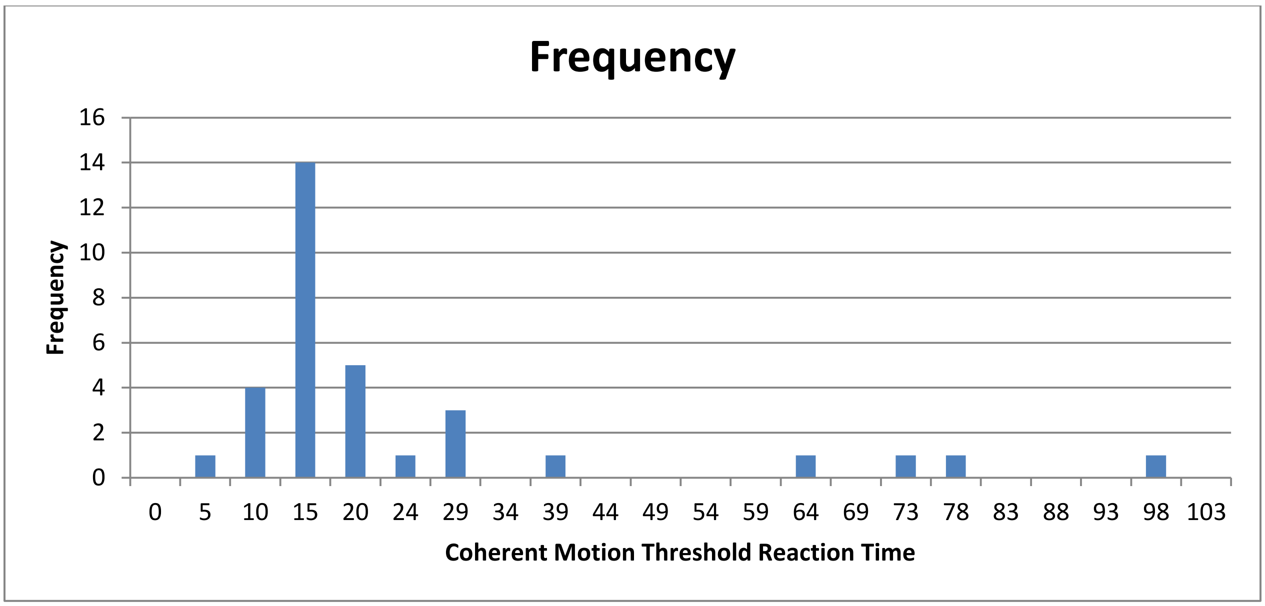
Graph 1.1



Chi-Square test for normality was used to test the null hypothesis (H_0) that the data has a normal distribution. The Chi-Squared Score (*df* = 5) = 32; p=3.99513x10^{-6}. The results indicated with $\alpha = 0.05$ that the null hypothesis can be rejected and the data are not normal.

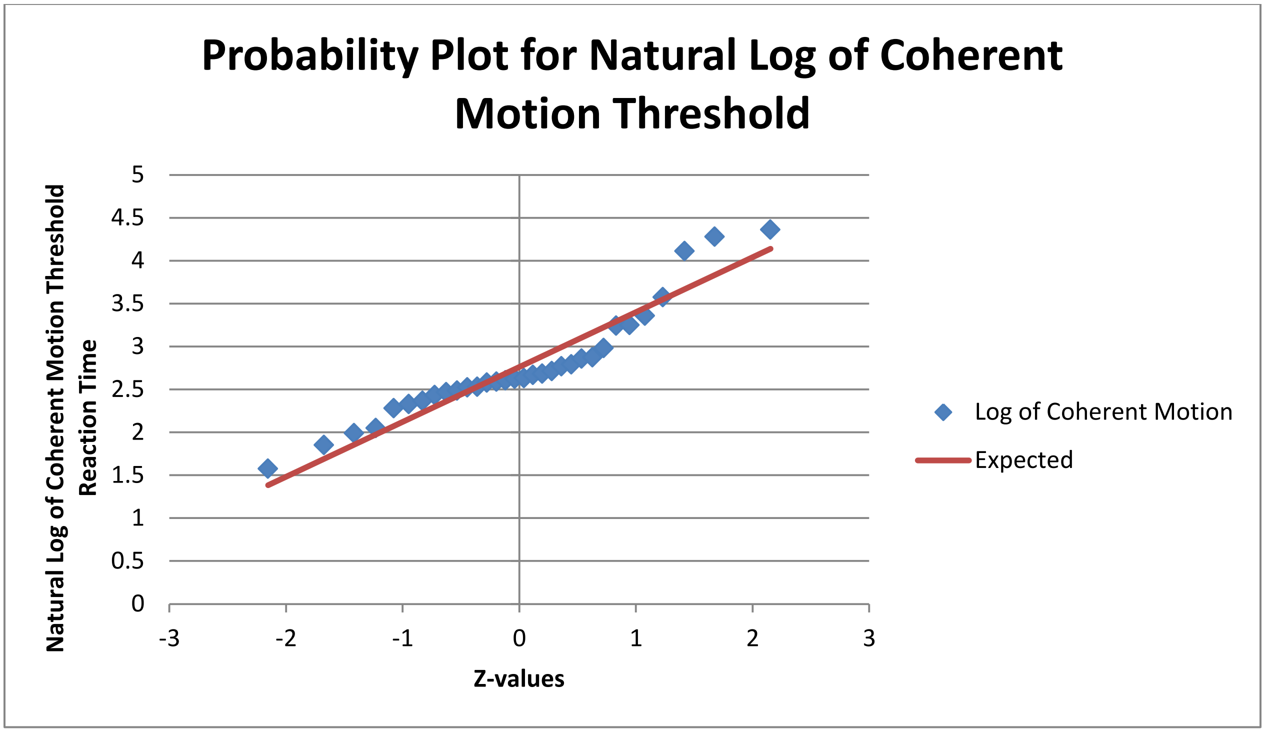
Due to the lack of normalcy indicated by the Chi-Square Test, a transformation of the data was needed. Frequency distribution of coherent motion was then used to determine what type of transformation might be used to normalize the data (see Graph 1.2).

Graph 1.2



A natural log transformation was used to transform the data for testing. A new probability plot using this data was created and a Chi-Squared test for normality was run (see Graph 1.3).

Graph 1.3



Chi-Squared Test for normality of the transformed data resulted in a Chi-Squared Score (*df* = 5) = 7.099; p= 0.213371. Therefore, using α = 0.05, the data can be considered normal to meet the assumptions for statistical analysis. A slight skew of 0.97 will not have any significant effect on analysis. The table below provides a summary of the descriptive statistics conducted for the study.

Table 4.

Descriptive Statistics for the Study

	PSI SCORE	***ln(Coherent Motion)***	***WJIII – Math Calc***	***WJ III - Math Fluency***
Mean	96.22	2.76	97.90	94.90
Standard Error	2.88	0.11	3.16	3.19
Median	97	2.63	95.5	93
Mode	100		95	96
Standard Deviation	15.72	0.64	17.86	18.06
Sample Variance	247.08	0.41	318.99	326.09
Kurtosis	-1.03	1.19	-0.38	-0.66
Skewness	0.21	0.96	-0.17	0.39
Significantly Skewed	No	Yes	No	No
Range	55	2.78	70	66
Minimum	73	1.57	61	66
Maximum	128	4.35	131	132
Sum	3079	88.37	3133	3037
Count	32	32	32	32

A Correlation Matrix was made to show correlations between all of the variables that were tested. PSI had a negative relationship to CMT and a positive correlation with both Math Fluency and Math Calculation. CMT had a negative relationship with math fluency and math calculation. Table 5 shows how each variable was related to each of the other variables.

Table 5

Correlation Matrix

	PSI SCORE	*COHERENT MOTION*	*WJIII - Calc*	*Fluency*
PSI SCORE	1			
COHERENT MOTION	-0.30	1		
WJIII - Calc	0.73	-0.33	1	
Fluency	0.70	-0.24	0.83	1

Hypothesis One

A linear regression model was used to determine if a relationship exists between CMT and PSI. To determine if a relationship exists between CMT and PSI, the Dependent Variable (DV) was defined as PSI and the Independent Variable was Coherent Motion (CMT). The variables were used to test the null hypothesis.

H_0: $\hat{Y} = B_0 + B_1X_1$, where $B_1 = 0$

H_A: B_1 does not equal 0

A scatter plot was created to determine possible trends in the data. The results indicated that a negative relationship exists between PSI and CMT. Analysis of Variance (ANOVA) was conducted to test Hypothesis I (Graph 1.4)

Graph 1.4

PSI and CMT

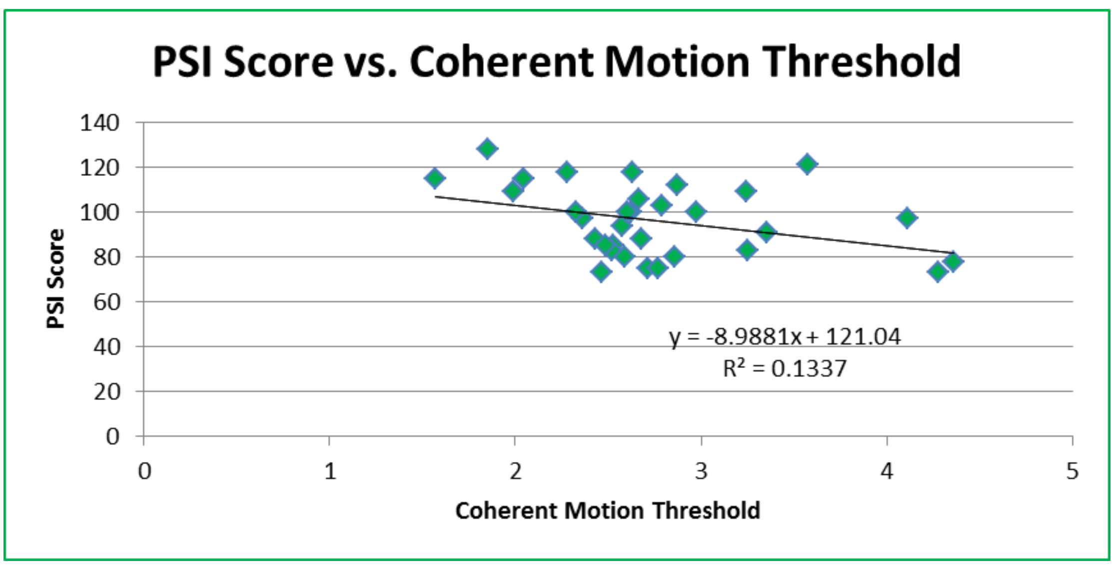


Table 6

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.37
R Square	0.13
Adjusted R Square	0.10
Standard Error	14.90
Observations	32

Table 6.1
ANOVA: HYPOTHESIS 1

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1024.36	1024.40	4.63	0.04
Residual	30	6635.11	221.20		
Total	31	7659.50			

An F- score was calculated to determine the significance in the ANOVA results. The F-score of 4.63 has significance of 0.04 ($p<0.05$). This result allows us to reject the null hypothesis and state that there is 95% confidence that a relationship exists between CMT and PSI. Residuals do not show a pattern indicating a good fit for a linear model. The model constructed has correlation (R) of -0.37 and an R^2 of 0.13 suggesting a moderate negative relationship. This model is able to show that 13 % of the variation in PSI score is explained by CMT.

Hypothesis Two

A regression model was used to test for a possible positive relationship between PSI and a child's performance on math fluency and math calculation. It was hypothesized that a positive relationship exists between a PSI score and scores on measures of math fluency and math calculation. Based on measurements from the Woodcock Johnson III (math fluency and math calculations), WISC-IV (PSI), and Psykinematix software program (CMT), students diagnosed with a learning disability in math fluency and math calculation did have lower PSI scores, suggesting that math fluency and math calculation is impacted by processing speed. Conversely, results indicated that the typically developing students had average or above average PSI scores and average or above average scores on math fluency and math calculation.

Hypothesis 2 was tested using a regression analysis of variance (ANOVA) test with alpha = 0.05. The ANOVA was used to show the relationship between math fluency and PSI, math calculation and PSI, and math calculation along with math fluency and PSI. The dependent variable used in these regression models was PSI. The independent variables used in this study were math fluency and math calculation, tested both independently and then combined.

The null hypothesis states: A low score on PSI has no association with low scores on measures of math fluency and math calculation. The alternative hypothesis is that there is a significant association. These are represented by the following equations:

H_0: $Y_{PSI} = B_0 + B_1X_{MF} + E$, where $B_i=0$

H_A: $B_1 \neq 0$, for any i

H_0: $Y_{PSI} = B_0 + B_1X_{MC} + E$, where $B_i=0$

H_A: $B_1 \neq 0$, for any i

H_0: $Y_{PSI} = B_0 + B_1X_{MF} + B_2X_{MC} + E$, where $B_i=0$

H_A: $B_1 \neq 0$, for any i

The ANOVA test began with calculation of the independent variable means across all dependent variable groups and within each dependent variable group as shown in Table 7. Table 7 indicates the results of regression analysis for Math Fluency and PSI. The model has an F value of 0.00 indicating significance. The R square value of 0.50 indicates that the model explains 47% of the variance in the PSI scores. This indicates that a strong direct relationship exists between math fluency and processing speed.

Table 7:

Regression Model – Math Fluency and PSI

Regression Statistics	
Multiple R	0.70
R Square	0.50
Adjusted R Square	0.50
Standard Error	11.50
Observations	32

Table 7.1

ANOVA Hypothesis 2a

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3710.80	3710.80	28.20	9.71516×10^{-06}
Residual	30	3948.71	131.62		
Total	31	7659.50			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	38.71709	11.01785	3.51	0.00
Fluency	0.605879	0.114108	5.30	9.72×10^{-06}

Another ANOVA test was run using the same means, but substituting math calculation for the independent variable. The results are shown in Table 8, which displays the results of regression analysis for Math Calculation and PSI. This model, just as the previous model, has an F value of 0.00 indicating significance. The R square value of 0.51 that the model explains 51% of the variance in the PSI scores. This indicates that a strong direct relationship exists between math calculation and PSI. A correlation of 0.73, as shown in Table 8, indicates that there is a strong positive relationship between PSI and math calculation.

Table 8

Regression Model – Math Calculation and PSI

Regression Statistics	
Multiple R	0.73
R Square	0.52
Adjusted R Square	0.51
Standard Error	11.00
Observations	32

Table 8.1

ANOVA Hypothesis 2b

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4035.00	4035. 20	33.40	$2.59001\text{x}10^{-06}$
Residual	30	3625.00	120.81		
Total	31	7659.50			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	33.67878	11.00	3.06	0.00
Calc	0.638774	0.11	5.90	$2.59\text{x}10^{-06}$

A multiple linear regression analysis model was used to determine if a correlation exists between two dependent variables (math fluency and math calculation) and one independent variable PSI. The results are displayed in Table 9, which shows the results of the multiple regression analysis for Math Fluency and Math Calculation with the independent variable PSI. This model has an F value of 0.00 indicating significance. The R square value of 0.53 indicates, based on the model, that 53% of the variance in the PSI scores can be explained by the influence of Math Fluency and Math Calculation together. This correlation implies that scores on both Math Fluency and Math Calculation will have a positive correlation with the PSI score. Based on the P-value of the independent variables Math Calculation has a more significant impact on PSI than Math Fluency. Math Calculation meets the threshold for significance (alpha =0.05) in the model while Math

Fluency does not. This suggests that even though Math Fluency is a predictor of PSI scores, using it along with Math Calculation won't significantly improve the model.

Table 9:

Regression Model – Math Fluency + Math Calculation and PSI

Regression Statistics	
Multiple R	0.74
R Square	0.60
Adjusted R Square	0.52
Standard Error	10.82
Observations	32

Table 9.1
ANOVA Hypothesis 2c

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	4259.04	2129.52	18.20	7.69776×10^{-06}
Residual	29	3400.43	117.30		
Total	31	7659.50			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	30.21	11.12	2.71	0.010
Calc	0.42	0.20	2.16	0.04
Fluency	0.36	0.20	1.38	0.20

Hypothesis Three

A multiple linear regression model was used to determine if a low score on PSI combined with a CMT score has a positive relationship with scores on measures of math fluency and math calculation. Dummy coding was implemented to test the hypothesis. A dummy code of 'zero' was used to indicate the typical developing students and a dummy code of 'one' was used to indicate the students with disabilities. The independent variables were the dummy score, the dummy score times the PSI score, and the dummy score times CMT results. The Dependent Variables (DV) were defined as Math Calculation in the first test and Math Fluency in the second test. It was hypothesized that a score on the PSI combined with the CMT is associated with scores on measures of math fluency and math calculation. The null hypothesis and the alternative hypothesis were as follows:

H0: $Y_{MC} = B_0 + B_1 X_{DS} + B_2 X_{DS} * X_{PSI} + B_3 X_{DS} * X_{CM} + E$; Every $B_i = 0$

H_A: Any B_i Does not equal 0

H0: $Y_{MF} = B_0 + B_1 X_{DS} + B_2 X_{DS} * X_{PSI} + B_3 X_{DS} * X_{CM} + E$; Every $B_i = 0$

H_A: Any B_i Does not equal 0

The first multiple regression model for math calculation had a F value of 0.00 and an R Square of 0.52 suggesting that the model is significant and explains 52% of the variance in math calculation. An examination of the P-value scores for students with a disability (P-value for PSI = 0.17 and P-value for CMT = 0.32) within the model do not show statistical significance. Even though the model indicates significance in predicting math calculation based on PSI, the combination of PSI and CMT does not appear to strengthen the ability of the model to predict performance on measures of math calculation.

Table 10

Multiple Regression Model for Predicting Math Calculation

Regression Statistics	
Multiple R	0.80
R Square	0.60
Adjusted R Square	0.52
Standard Error	12.40
Observations	32

Table 10.1

ANOVA Hypothesis 3a

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	5616.80	1872.30	12.30	2.63929×10^{-05}
Residual	28	4272.00	152.57		
Total	31	9888.72			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	110.13	3.09	35.70	6.99458×10^{-25}
DS	-61.00	48.81	-1.24	0.22
DS * PSI	0.63	0.50	1.40	0.17
DS * CM	-6.00	5.90	-1.00	0.32

To determine if PSI and CMT, along with being identified as disabled, can be used as a predictor for math fluency scores, a second multiple regression model was created. Math Fluency had an F value of 0.00 and an R Square of 0.43 suggesting that the model is significant and explains 43% of the variance in math fluency. An examination of the P-value scores for students with a disability (P-value for PSI = 0.23 and P-value for CMT = 0.46) within the model do not show statistical significance. Even though the model indicates significance in predicting math calculation based on PSI, the combination of PSI and CMT does not appear to strengthen the ability of the model to predict performance on measures of math fluency.

Table 11

Multiple Regression Model for Predicting Math Fluency

Regression Statistics	
Multiple R	0.70
R Square	0.50
Adjusted R Square	0.43
Standard Error	13.70

Observations	32

Table 11.1
ANOVA Hypothesis 3b

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	4865.50	1621.90	8.66	0.000317388
Residual	28	5243.22	187.30		
Total	31	10108.72			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	106.31	3.42	31.08	$3.01181\text{x}10^{-23}$
DS	-61.20	54.08	-1.13	0.27
DS * PSI	0.61	0.50	1.23	0.22
DS * CM	-4.82	6.48	-0.74	0.50

Summary

Results from analyzing data relative to Hypothesis One showed that there was a weak negative correlation between PSI and CMT. Only 13% of the variation in PSI could be explained by CMT scores. Results from analyzing data relative to Hypothesis Two showed strong correlations between both Math Fluency and PSI scores as well as between Math Calculation and PSI scores. This suggests that there is a significant relationship existing between PSI and performance on math fluency and math calculation. Results from analyzing data relative to Hypothesis Three indicated that, taking into account students' learning disability status, coupled with the combination of PSI and CMT scores, they do not improve ability of the model to predict math calculation and math fluency scores.

Chapter 5

Summary and Discussion

This chapter restates the problem of the study and reviews the methodology that was used to carry out the study. The remaining sections of this chapter summarize the results of the project, discuss the results, as well as discuss the possible implications of the study. The chapter concludes with recommendations for further research.

There has been a considerable amount of research carried out on reading and learning to read which that has led to some important findings on children with reading disabilities. Yet, there have been relatively few studies on mathematics and learning disabilities related to mathematics, when compared to the number of studies on reading. The purpose of this study was to determine the following research questions:

Is there an inverse relationship between PSI and CMT?

Is a score on PSI associated with a child's performance on math fluency and math calculation?

Is CMT associated with PSI or math fluency and math calculation?

Processing speed was measured using the Processing Speed Index (PSI) on the WISC IV, the coherent motion threshold was determined using the Psykinematix software program, and academic performance in math was measured using the Woodcock Johnson Tests of Achievement, third edition, math fluency and math calculation subtests.

This study investigated the likelihood that a child with a low PSI will have a high CMT. Low sensitivity to coherent motion would suggest a deficit in the M-pathway, which is suspected to result in an individual's difficulty to process routine visual information. Such a deficit can lead to significant problems in learning. Research by Sigmundsson et al. (2010) and Boets et al. (2011)

support a connection between PSI and math performance. Their research suggests that children with a deficit in the M-pathway will have difficulty developing pattern recognition and visual number relationships, which may lead to a difficulty with math fluency and math calculation. Therefore, a deficit in the M-pathway might negatively impact an individual's ability to succeed in math.

Review of Methodology

As explained in Chapter 3, this quantitative study was comprised of 33 students from grades 2 to 8. As mentioned in chapter 4, one outlier was identified within the Coherent Motion data. This student's data was removed from the sample, leaving 32 students' data in the study. All subjects in the study were matched as closely as possible to categories of average IQ scores and ages. The students were broken into two groups. Group One consisted of four children with a learning disability in math only and thirteen children with a learning disability in reading and in math. Group Two consisted of 16 typically developing children. A group of typically developing subjects served as the control group, and the remaining two groups served as the experimental groups.

Participants for the study were obtained from four public schools in districts and one private parochial school. The Director of Special Education was contacted in each of the school districts that participated in the study. The Special Education Director from each district participating in the study was given the parameters for students in each group. Special Education teachers within each district were contacted to identify potential participants who met the established criteria for each group. The teachers identified the students that met the parameters for the study and contacted the children's parents. Once parent permission was obtained, the researcher gave a letter explaining the project to each of the children asking for his or her permission to participate in the project. After the children gave their permission to participate in the study, testing began. The study consisted of 32 participants: 2 eighth graders, 5 sixth graders, 12 fifth graders, 2 fourth graders, 4 third graders, and

8 second graders. Each student was given an eye exam using the Snellen chart which is used by school nurses to measure visual acuity.

The principal at the parochial school was contacted. The principal read the proposal and agreed to participate. She contacted each parent and obtained permission to test.

Data collection occurred over a 14 month period. The researcher went to each school, and met with the children to administer an informal vision acuity screening. Students passing the screening were then administered the math fluency and math calculation subtest, the CMT and PSI subtests. Testing for each child was completed within a 45-minute period. Results were sent home to parents explaining the results of the evaluation. (See Appendix D)

Summary of Results

Three hypotheses were developed to guide this study. The results of the study relative to each of these hypotheses will be discussed:

- Hypothesis #1: There is an inverse relationship between PSI and CMT
- Hypothesis # 2: There is a positive relationship between a PSI score and the scores on measures of math fluency and math calculation.
- Hypothesis #3: When a low PSI score is combined with high CMT a positive relationship will result with scores on measures of math fluency and math calculation.

A linear regression model was used to determine if a relationship exists between CMT and PSI. The Dependent Variable (DV) was defined as PSI and the Independent Variable as CMT. Analysis of Variance (ANOVA) was conducted to test Hypothesis I. The results indicated that a negative relationship exists between PSI and CMT, although the model was only able to show that 13 percent of the variation in PSI score is explained by CMT.

Hypothesis two was tested using a regression analysis of variance (ANOVA) test with alpha = 0.05 to determine if PSI is associated with scores on measures of math fluency and math calculation. ANOVA was used to show the relationship between math fluency and PSI, math calculation and PSI, and math calculation along with math fluency and PSI. The dependent variable used in these regression models was PSI. The independent variables were math fluency and math calculation, tested both independently and then combined. Results indicated that a strong direct relationship does exist between math fluency and PSI, and there is a strong positive relationship between PSI and math calculation.

Hypothesis three was tested with a multiple linear regression model to determine if a score on PSI combined with a CMT score is associated with scores on measures of math fluency and math calculation. Results indicated that the combination of PSI and CMT scores do not strengthen the ability of the model to predict performance on measures of math calculation or fluency.

Limitations of the Study

The study was limited by the relatively small sample size, making it difficult to generalize these results to larger populations. Securing participants proved highly difficult because of reluctance of districts to participate, and the reluctance of parents to grant permission for the testing required in the districts that did agree to participate. In one case, a district agreed to participate, however the special education teacher was not comfortable with that decision and may have discouraged parents from granting the necessary permissions to proceed. Another limitation to the study was the lack of control over the testing that had been done previous to this study to identify students as learning disabled. Although districts were required to follow state guidelines in testing to identify students with a learning disability, there was no way to control for variations in the process, including instruments used, uniformity of administration, and student rapport with examiners.

Additionally, there was no way to control for when the subjects had been identified as learning disabled, i.e. some may have been identified early in their schooling, some may have recently been identified, and some may have been identified in a different district or state and then transferred into their current district.

The study was originally intended to focus on second and third grade students with a balance of boys and girls, however due to the difficulty in securing volunteers, the scope of the study was expanded to include second through eighth grade students, and gender balance was not able to be obtained. Additionally, although students received monetary compensation for their time, they were told that their participation in this study would not have any impact on their grades; therefore it is possible that some may not have given their best effort.

Discussion of Results

This study examined the association of neurological factors, specifically CMT and PSI, on performance in mathematics. The results found that there is a moderate negative association between CMT and PSI. The results indicated that a low PSI score is generally associated with a high CMT score for most students.

Hypothesis one speculated that an inverse relationship exists between PSI and CMT. The model constructed found a correlation (R) of - 0.36 and an R^2 of 0.13 suggesting a moderate negative relationship. This model was only able to show that 13 % of the variation in PSI score could be explained by CMT. It is important to note that visual processing consists of many skills and abilities. Schneider and McGrew (2013) point out once people know how to perform a task, the speed and fluency in which the task is carried out will differ due to the factors that make up one's processing speed. Dr. R. Mangen (n.d.) states that the research on processing speed has identified three different kinds of processing speed abilities: perceptual speed which is the ability to quickly seek and compare visual patterns or symbols when presented next to one another or separated within a visual array; number facility which is the ability to quickly and accurately deal with numbers and basic numerical calculations; and rate-of-test-taking which is the ability to quickly carry out easy tasks or tasks that demand very simple decisions. These processing speed abilities are supported by the Cattell-Horn-Carroll (CHC)'s Model of Intelligence Theory. According to the CHC Model, the two tasks required by the subjects in this study called for the subjects to use perceptual speed. Perceptual Speed is the speed at which visual stimuli is compared for similarities and differences. Research (Ackerman, Beier, & Boyle, 2002) suggests that Perceptual Speed may consist of various abilities (between narrow and broad) which include Pattern Recognition, Scanning, and Memory.

Coherent Motion Threshold required the subjects to use Reaction and Decision Speed. Reaction and Decision Speed is the speed with which one can make very simple decisions when items are presented one at a time. This involves various skills such as simple reaction time, mental comparison speed and inspection time. A simple reaction time to a single visual stimulus is a simple task that can be divided into two phases: first is decision time, which is the time to decide to make a response and the finger leaves a home button, and second is movement time, which is the time to move the finger from the home button to another button where the response is physically made and recorded (Schneider & McGrew, 2013). Mental Comparison Speed is the reaction time where stimuli is compared for a particular characteristic or attribute. The Inspection Time is the speed at which differences in stimuli can be perceived (Schneider and McGrew, 2013). These factors are required to detect one's coherent motion threshold (CMT).

Dr. R. Mangen (n.d.) mentions that processing speed is affected by several neurological factors, such as the balance and the ability of the neurotransmitters in the brain, the development of the myelin sheath which is involved with the relaying of information along the nerves, the size of the synaptic gaps between nerves, and the overall ability of the frontal lobes which are involved in organization and direction of the flow of information. When one considers all of the factors that are required for PSI and CMT, 13% could be considered significant.

Analysis of the PSI scores for the students with a disability in math only revealed PSI standard scores ranging from 97 to 73, with a range of 24 points. While there were only four students in this group, the average of the four scores came to 81. Only one of the four students obtained a PSI score in the average range (90 - 109) with a standard score of 97. The other three scores fell below one standard deviation from the mean. Of the four students within this group, only one was a fifth grader and the other three were in the sixth grade, and only the fifth grader scored within the average range for PSI. A group of four students is too small to draw a firm conclusion; however, it appears that students with a disability in math may have a weak PSI score.

Twelve students were in the group of students with a disability in both reading and math. PSI standard scores for this group ranged from 100 to 75, a range of 25 points, with an average score of 86.25. The median score was 83, and no mode was found among the scores. Eight of the twelve students in this group had a PSI score at or below one standard deviation from the mean, and only three students had a PSI within the average range. No one in this group had a PSI above 100. No difference in scores was found among the various grade levels. Based on these results, it can be implied that students with a learning disability tend to have a weak PSI.

When both groups of students with disabilities were combined the average score was 82.58, with a mean of 83, and a mode of 80 and 75. Scores ranged from 100 to 73, a range of 27 points. The average of all PSI scores from both groups equaled 85, which is one standard deviation from the mean. Eleven of the 16 students with a learning disability had a standard PSI score at or below one standard deviation from the norm; only three of the students had a PSI score within the average range.

Standard PSI scores for typically developing students ranged from 128 to 73, a range of 55 points. Of the 16 students in this group, only one student's score fell below one standard deviation below the mean with a standard score of 73. Seven students' scores fell within the average range, six fell over one standard deviation above the mean, and two students fell within the high average range. The group's average score was 107.75, with a median score of 109, and a mode score of 100.

No difference was found between the students diagnosed with a learning disability in math only students and those diagnosed with a learning disability in both reading and math. The majority of the students within the two groups had scores falling below one standard deviation from the mean. Significant differences were found when these groups were compared to the typically developing students. Fifteen of the sixteen students in the typically developing group had scores within the average to superior range, while only three students with a disability had PSI scores in the average range, and no one had a score above 100. This suggests that based on the results of this study, students with a learning disability have a slower visual processing speed which may make learning more difficult and impact their ability to recall basic math facts. These results also indicate that students with high PSI scores may perform well on academic tasks.

Group One's CMT results (those with a learning disability in math only) reveal that all four students had CMT averages above 10. One student in this group had a CMT result of 72. The average CMT result was 27.7. Group Two's students (those with a disability in both reading and math), had CMT results which ranged from 78.25 to 11.3 (a range of 67), with a median resulting in 13.7 and an average of 21.3. Three students had results over 20. Nine students had average CMT results that were between 11 – 17.3.

Students in Group Three (the typically developing group), had CMT results ranging from 60.9 to 4.82 resulting in a range of 56 points. This resulted in the average score of 17.1 and a median score of 13.5. Six students had CMT results at or below 10.2 and four students had results between 11.7 and 14.0; and three students had results between 16.2 and 19.6, leaving three students with scores above 20.

CMT results revealed that all of the students in the Groups 1 and 2 had a reaction time above 10. Eight out of sixteen of the students with a learning disability had reaction times at or above 15, with results ranging from 78.25 to 11.3. Group 3 had 6 out of 16 students with reaction times below 10, and 4 had reaction times between 10 and 15, leaving 6 students with reaction times above 15, with results ranging from 60.9 to 4.8.

Some differences were found among the groups. No significant differences were found among the CMT results among students in Groups 1 and 2. Both group averages were above 20 for CMT results. No one in either of the two groups with disabilities had results below ten, while six of the typically developing group had CMT results at 10 or below. The average result in the Group 3 was 17.

The ten point difference in CMT averages between Groups 1 and 3 (an average of 27.1), and Group 3 (an average of 17.3), was impacted by outlier scores. One student in Group 1 averaged 72, and in Group 2, one student had an average of 78.25. In Group 3, one student had an extreme result of 60.9. When these scores are removed, the results are not very significant. Group 1 has an average of 12.8, Group 2 has an average of 16 and Group 3 has an average of 14.2. Based on the results of this study, students with a learning disability may have a slower CMT than those students without a learning disability; however, a larger sample size would be needed to generalize these results.

Three of the four students in Group 1 had a high CMT score (above 12) and had a low PSI score (below 85). All twelve students in Group 2 had a CMT score (at or above 11), and of those 12 students, 9 had a PSI score at or below 85. Therefore, 10 out of 16 students that had a CMT score at or above 11 had a PSI score that was at or below 85. Among the typically developing students in Group 3, 6 of the 16 students had a CMT score below 10 and a PSI score at or above 100, while 8 of the 16 students had CMT scores at or above 14, and PSI scores were within or above the average range.

Hypothesis Two speculated that PSI score is associated with the scores on measures of math fluency and math calculation. The model explains 47% of the variance in the PSI scores. This indicates that a strong direct relationship exists between math fluency and PSI. This study supports the Bull and Johnston (1997) study which found that children with difficulties in arithmetic have significant problems in the automaticity of basic arithmetic facts and concluded that this may stem from a general speed-of-processing deficit.

A strong correlation also exists between math calculation and PSI. The R square value of 0.51 explains 51% of the variance in the PSI scores, and indicates that a strong direct relationship exists between math calculation and PSI.

Close analysis of the PSI subtest scaled scores revealed that only one student in both Groups 1and 2 had a scaled score above average on the Coding subtest (10 is average), all other scores fell below average. Scaled scores ranged from 11 to 2 for Group 1 and Group 2. Analysis of the Group 3's Coding subtest scores revealed 12 of the 16 students' scores fell at or above average while only 4 students' scores fell below the average scaled score of 10 (3 students obtained a scaled score of 9 and one obtained a scaled score of 5). The typically developing students' scaled scores ranged from 17 to 5.

Analysis of the Symbol Search subtest revealed a similar pattern. The typically developing group performed higher than the two groups with a disability. Scaled scores for Group 1 and Group 2 ranged from 11 to 5, with 13 of the 16 participants' scores falling below the average score of 10, while only 3 participants scored at or above average, with scaled scores of 11. The typically developing group's scores, with scores ranging from 17 to 5, revealed 14 of the 16 participants' scored at or above 10, while only 2 participants' scores were below average (one scoring 5 and the other scoring 9). Based on the results of this study, students with a learning disability tend to have a lower PSI.

PSI scores were compared to math calculation and math fluency scores. Three out of four participants in Group 1 had a low PSI score (below one standard deviation from the mean), and a low math fluency score at or below one standard deviation from the mean. This group had an average math fluency score of 82, which is below one standard deviation from the mean.

Five out of twelve participants in Group 2 had PSI scores at or below one standard deviation from the mean and had math fluency scores at or below one standard deviation from the mean. Group 2's average math fluency score was 84, which was also below one standard deviation. No participant in either Groups 1 or 2 had a math fluency standard score above 98. Only 7 out of the 16 participants in both groups had a math fluency score in the nineties.

The typically developing students' scores revealed the majority of participants scoring in the average or above average range on both PSI and math fluency, with 9 out of the 16 students having PSI and math fluency scores at or above average (standard score at or greater than 100) and only 3 out of 16 students with math fluency scores at or below one standard deviation below the mean (standard score less than 85). Only one student had both a PSI and math fluency score both below one standard deviation. The average math fluency score for the typically developing students was 96, which is within the average range (90 – 109).

Math calculation scores in the math only group revealed that 2 out of the 4 students had scores at or below one standard deviation below the mean (standard scores of 86 and 66 on math calculation). Two of the students had math calculation scores within the average range (standard scores of 92 and 96). Only one participant had both PSI and Math Calculation scores that were both over one standard deviation below the norm.

Six students with a disability in both reading and math had math calculation scores above 90 with standard scores ranging from 91 to 101. Five students had both PSI and Math Calculation scores at or below one standard deviation from the norm. The average math calculation score was 87, which is two points above one standard deviation of 15 points.

All of the 16 students within Group 3 had standard scores at or above 90 on Math calculation. Math calculation scores ranged from 90 to 131, with an average score of 110.1.

Flanagan, Ortiz, & Alfonso (2007) claim that PSI is important in the assessment of cognitive ability and state:

> Many cognitive activities require a person’s deliberate efforts and people are limited in the amount of effort they can allocate. In the face of limited processing resources, the speed of processing is critical because it determines in part how rapidly limited resources can be reallocated to other cognitive tasks (pps. 291-292).

Processing speed is a component of intelligence, and included as part of The Cattell–Horn–Carroll Theory (Flanagan, Ortiz, & Alfonso (2007); and therefore, influences student performance in the classroom. Math fluency is a basic fundamental of mathematics; therefore one’s ability to do well on math calculation is dependent on one’s math fluency (National Mathematics Advisory Panel, 2008). A lack of fluency in basic arithmetic can be devastating to the comprehension of more complex math concepts such as fractions and decimals (National Mathematics Advisory Panel, 2008). Math fluency allows students to gain automaticity of basics in arithmetic which opens up space in the working memory for more complex mathematical problem solving ability (National Mathematics Advisory Panel, 2008).

In this study 6 out of 16 students with learning disabilities had both PSI and math fluency scores that fell at or below 85, while only 1 out of 16 typically developing students had both math fluency score and PSI scores at or below one standard deviation below the norm. These results seems to support that low processing speed will influence math fluency which in turn may impact one's ability to calculate and compute higher, complex problem solving.

Hypothesis 3 speculated that the combination of PSI and CMT scores is associated with scores of math fluency and math calculation. While a direct relationship between PSI and performance on measures of math calculation and fluency was found to exist, the combination of PSI and CMT was not found to strengthen the ability of the model to predict performance on either math calculation or math fluency.

Based on the results of this study, PSI is definitely related to math fluency and math calculation. Coherent motion does not appear to be influential in predicting performance on measures of math fluency or math calculation. These findings do not support the findings of a study conducted by Cornelissen et al. (1994), that found that students with dyslexia were significantly less sensitive to motion. Their study, which examined reading performance, suggested that developmental dyslexia may be associated with a magnocellular visual deficit. Results of the current study focused on the relationship between PSI and CMT and performance on measures of math calculation and fluency. Three of the four students in Group 1 had a high CMT score above 12 and had a low PSI score (below 85). All twelve students in Group 2 had a CMT score at or above 11 and a mean PSI score of 85. Typically developing students' CMT results revealed 6 out of 16 students' scores at or below 10, while the remaining 10 students' indicated results above 10. The mean PSI score for this group was 109. These results suggest that there may be some difference in CMT between those students with a learning disability and those without a learning disability. Based on these results, students with a disability tend to have a slower CMT.

Implications of the Study

Based on previous literature and observations, it had been speculated that a deficit in the M-pathway, may be partly responsible for deficits in math calculation and math fluency (Sigmundsson, Anholt, & Talcott, 2010). In an effort to explore this possibility, tests for both PSI and CMT were conducted in addition to tests of math calculation and fluency. The results of this study indicate a strong direct relationship between PSI and performance on measures of math calculation and math fluency. These findings support those of Bull and Johnson (1997) that indicated that processing speed might be another indicator of math abilities. Their findings indicated that, while there was a strong correlation between short-term memory and math ability, other factors were also to be considered. Results from the current study indicate that PSI may be useful in predicting which students may have difficulty with mathematics in the future. Results indicated a direct relationship between a low PSI score and low scores on math fluency and math calculation. Therefore, educators may want to consider using PSI as an early predictor of possible dyscalculia. The current study also investigated the potential usefulness of adding the CMT score as a second criterion in predicting math performance. Based on the Corneilsson et al. (1994) study, it was hypothesized that better understanding of the M pathway may provide further insight into a child's potential to struggle or be successful with mathematics. However, the results of this study seem to indicate limited usefulness of a combination of CMT and PSI in predicting math ability.

Recommendations for Further Study

Given the small sample size used in this study, it is recommended that the scope be expanded to include a larger group of students in order to make generalizations applicable to large populations. Because these results do not support those of several previous studies that have indicated deficits in the magnocellular pathway play a critical role in academic performance, it is recommended that further, more extensive investigation be undertaken to study the M-pathway and possible impact it may have on mathematics ability. It is further recommended that the CMT portion of the evaluation be conducted by an optometrist to provide a more in-depth interpretation of the results. It is also recommended that the psychologist administer a current intelligence measure and include each participant's intelligence in the model.

It is also recommended that other demographics be included in the study. It would be recommended that future studies include multi-cultural diversity among the subjects, as well as gender differences. This would provide for a more inclusive sampling of the total population.

Concluding Remarks

This study provides only a glimpse into the relationship existing between measurements and academic performance, like the PSI and CMT, have on mathematics. The results suggest that a moderate negative relationship exists between PSI and CMT. The model was able to show that 13 % of the variation in PSI score could be explained by CMT. It must be remembered that visual processing consists of many skills and abilities. Based on these results it is suggested that this study be expanded to include more subjects so one could make a strong determination from the results. It is also suggested to study the percentage of impact perceptual speed has on processing speed.

The results of this study suggest that PSI is definitely related to math fluency and math calculation. Recognizing the impact of PSI on math fluency and math calculation begs the question: What impact does a low PSI have on student performance in other academic areas, such as reading and written expression? The IDEA law does not consider students with a low processing speed as a category for them to receive special education services. I believe further study in processing speed and the impact it has on dyslexia and dyscalculia is greatly needed. Hopefully these studies will find evidence to make provisions in IDEA to include processing speed as a category for special education.

This researcher intends to continue the study of processing speed by developing a qualitative study on the emotional impact a low processing speed has on elementary students' self-concept. It is hypothesized that students with a low processing speed will have a low self-concept.

References

Ackerman, P., Beier, M., & Boyle, M. (2002). Individual differences in working memory within a nomological network of cognitive and perceptual speed abilities. *Journal of Experimental Psychology: General*, *131*(4), 567-589.

Ackerman, P., & Cianciolo, A. (2000). Cognitive, perceptual-speed, and psychomotor determinants of individual differences during skill acquisition. *Journal of Experimental Psychology: Applied*, *6*(4), 259-290.

Amitay, S., Ben-Yehudah, G., Banai, K., & Ahissar, M. (2002). Disabled readers suffer from visual and auditory impairments but not from a specific magnocellular deficit. *Brain*, *125*(10), 2272-2284.

Arithmetic. (n.d.). In Merriam-Webster's onlilne dictionary (2015). Retrieved from http://www.merriam-webster.com/dictionary

Ashcraft, M. H. (1982). The development of mental arithmetic: A chronometric approach. *Developmental Review*, *2*, 213 – 236.

Axtell, P. K., McCallum, R.S., Bell, S. M., & Poncy, B., (2009). Developing math automaticity using a classwide fluency building procedure for middle school students: A preliminary study. *Psychology in the Schools*, *46*, 526-538.

Baddeley, A. D. (2000). The episodic buffer: a new component of working memory. *Trends in Cognitive Science, 4*, 417-423.

Badian, N.A. (1983). Dyscalculia and nonverbal disorders of learning. In H. R. Myklebust (Ed.), *Progress in Learning Disabilities, 5,* (pp. 235-264). New York, NY: Stratton.

Badian, N. A. (1999). Persistent arithmetic, reading, or arithmetic and reading disability. *Annals of Dyslexia*, *49*, 45-71.

Baroody, A. (1993). The relationship between the order-irrelevance principle and counting skill. *Journal for Research in Mathematics Education*, *24*, 415-427.

Baroody, A. (2008). *Fostering early number sense*. Keynote speech presented at the Banff International conference on Behavioural Science. Baniff, AB, Canada. Retrieved from http://www.excellence-earlychildhood.ca/documents/Arthur_BaroodyANG.pfd.

Blackorby, J., Chorost, M., Garza, N., & Guzman, A. (2007). The Academic Performance of Elementary and Middle School Students with Disabilities. As retrieved from: http://www.seels.net/designdocs/engagement/04_SEELS_outcomes_C4_8-19-04.pdf

Boden, C., & Brodeur, D. (1999). Visual processing of verbal and nonverbal stimuli in adolescents with reading disabilities. *Journal of Learning Disabilities*, *32*, 58-71.

Boden, C. & Giaschi, D. (2007). M-pathway Deficits and Reading-Related Visual Processes in Developemental Dyslexia. *Psychological Bulletin, 133*, 346-366.

Boets, B., De Smedt, B. & Ghesquiere, P. (2011). Coherent motion sensitivity predicts individual differences in subtraction. *Research in Developmental Disabilities*, doi:10.1016/j.ridd.2011.01.024.

Boets, B., Vandermosten, M., Cornelissen, P., Wouters, J., & Ghesquiere, P. (2011). Coherent motion sensitivity and reading development in the transition from pre-reading to reading stage. *Child Development*, *82*, 854 – 869.

Britten, K. H., Shadlen, M. N., Newsome, W. T., & Movshon, J. A. (1992). The analysis of visual motion: A comparison of neuronal and psychophysical performance. *Journal of Neuroscience, 12*, 4745–4765.

Bull, R., & Johnston, R.S. (1997). Children's arithmetical difficulties: Contributions from processing speed, item identification, and short-term memory. *Journal of Experimental Child Psychology, 65,* 1-24.

Bull, R., Johnston, R.S. & Roy, J.A. (1999). Exploring the roles of the visual-spatial sketchpad and central executive in children's arithmetic skills: Views from cognition and developmental neuropsychology. *Developmental Neuropsychology, 15*, 421-442.

Burns, M. K. (2005). Using incremental rehearsal to increase fluency of single-digit multiplication facts with children identified as learning disabled in mathematics computation. *Education and Treatment of Children, 28*, 237-249.

Butterworth B. (2010). Foundational numerical capacities and the origins of dyscalculia. *Trends in Cognitive Sciences, 14*(12), 534–541.

Carpenter, T. P., & Moser, J. M. (1983). The acquisition of addition and subtraction concepts. In the acquisition of mathematical concepts and processes. In Lesh, R. and Landau, M. (Eds.) *The acquisition of mathematical concepts and processes* (pp.7 – 44). New York: Academic Press.

Castles A, & Coltheart M (1993). Varieties of developmental dyslexia. *Cognition, 47*, 149–80.

Chalfant, J. C., & King, F. S. (1976). An approach to operationalizing the definition of learning disabilities. *Journal of Learning Disabilities, 9*, 228–243.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum. As retrieved from: http://ies.ed.gov/ncee/wwc/references/idocviewer/Doc.aspx?docId=19&tocId=8

Corbett, A. J., McCusker, E.A., Davidson, O.R. (1988). Acalculia following a dominant-hemisphere subcortical infarct. *Archives of Neurology*, *43*, 964 - 966

Cornelissen, P. L., Hansen, P. C., Gilchrist, I., Cormack, F., Essex, J., & Frankish, C. (1998). Coherent motion detection and letter position encoding. *Vision Research*, *38*, 2181-2191.

Cornelissen, P. L., Richardson, A.R., Mason, A., Fowler, M.S., & Stein, J. F. (1995). Contrast sensitivity and coherent motion detection measured at photopic luminance levels in dyslexics and controls. *Vision Research, 35*, 1483-1494.

Davenport, H. (1999), *The higher arithmetic: An introduction to the theory of numbers* (7th ed.). Cambridge, UK: Cambridge University Press.

Deary, I.J. (2001). Ageing and intelligence: senility or sagacity? In Deary, I.J. (2001) *Intelligence: A very short introduction* (pp. 19 – 42). New York: Oxford University Press.

Delazer, M., Domahs, F., Bartha, L., Brenneis, C., Locky, A., Trieb, T. & Benke, T., (2003). Learning complex arithmetic—an fMRI study. *Cognitive Brain Research, 18*, 76–88.

Delazer, M., Domahs, F., Bartha, L., Brenneis, C., Locky, A., & Trieb, T. (2004). The acquisition of arithmetic knowledge—an fMRI study. *Cortex, 40*, 166–167.

DeLuca, J. & Kalmar, J. H. (2008). *Information Processing Speed in Clinical Populations*. New York: Taylor and Francis, Inc.

Deary, I.J. & Stough, C. (1996). Intelligence and inspection time: Achievements, prospects, and problems. *American Psychologist*, *51,* 599-608.

Dehaene, S., & Cohen, L. (1991). Two mental calculations systems: A case study of severe acalculia with preserved approximation. *Neuropsychologia*, *29*, 1045-1074.

Dehaene, S. & Cohen, L. (1995). Towards an anatomical and functional model of number processing. In B. Butterworth, *Mathematical Cognition*, *1,* 83 – 120.

Dehaene, S. (2001). The cognitive neuroscience of numeracy: Exploring the cerebral substrates, the development, and the pathologies of number sense. In S. M. Fitzpatrick and J.T. Bruer (Eds.), *Carving our destiny: Scientific research faces a new millennium* (p. 41-76). New York, NY: John Henry Press.

Dehaene, S., Piazza, M., Pinel, P., & Cohen, L. (2003). Three parietal circuits for number processing. *Cognitive Neuropsychology, 20*, 487 – 506.

Delazer, M., Domas, F., Bartha, L., Brennis, C., Locky, A., Trieb, T., & Benke, T. (2003). Learning complex arithmetic: An MRI study. *Cognitive Brain Research*, *18,* 76-88.

Demaree, Heath A., Frazier, Thomas W., & Johnson, Courtney E. (2008). Information processing speed: Measurement issues and its relationships with other neuropsychological constructs. In John DeLuca and Jessica H. Kalmar (Ed.*) Information Processing Speed in Clinical Populations* (pp. 53 – 77). New York, NY: Taylor and Francis.

Dempster, F.N. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review*, *12*, 45-75.

Denckla, M.B., & Rudel, R.G. (1976). Rapid "automatized" naming (R.A.N.): Dyslexia differentiated from other learning disabilities. *Neuropsychologia*, *14*, 471-479.

Desoete, Annemie, Roeyers, Herbert, & De Cleroq, A. (2004). Children with mathematics learning disabilities in Belgium. *Journal of Learning Disabilities*, *37*, 50-61.

Donders, J., Tulsky, D.S. & Zhu, J. (2001). Criterion validity of new WAIS-III subtest scores after traumatic brain injury. Journal of the International Neuropsychological Society, *7*, 892-898.

Dougherty, T.M. & Haith, M.M. (1997). Infant expectations and reaction times as predictors of childhood speed of processing and IQ. *Developmental Psychology, 33,* 145 – 155.

Dumont, R. and Willis, J. (2002). Woodcock Johnson III. As retrieved from http://alpha.fdu.edu/psychology/woodcock_ach_descrip.htm.

Eden, G & Zeffiro T, (1998). Neural systems affected in developmental dyslexia revealed by functional neuroimaging. *Neuron, 21*, 279-282.

Ferguson, A.N. & Bowey, J.A. (2005). Global processing speed as a mediator of developmental changes in children's auditory memory span. *Journal of Experimental Child Psychology, 28*, 998-1005.

Fiez J.A. & Petersen, S.E. (1998). Neuroimaging studies of word reading. *Proc. National Academy of Science. U.S.A., 95*, 914–21.

Flanagan, D.P., & Kaufman, A.S. (2004). *Essentials of WISC-IV Assessment*. Hoboken, NJ: John Wiley and Sons, Inc.

Flanagan, D.P., Ortiz, S.O., & Alfonso, V.C. (2007). *Essentials of Cross-Battery Assessment, 2nd Edition*, Hoboken, NJ: John Wiley and Sons, Inc.

Forness, S., Sinclaair, E., & Guthrie, D. (1983). Learning Disability Discrepancy Formulas: Their use in actual practice. *Learning Disability Quarterly*, *6*(2), 107-115.

Frankenberger, W., & Fronzaglio, K. (1991). A review of states' criteria and procedures for identifying children with learning disabilities. *Journal of Learning Disabilities, 24*, 495–500.

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: True isses and false trails. *Psychological Bulletin, 123*, 71 – 99.

Fry, A. F., & Hale, S. (1996). Processing speed, working memory , and fluid intelligence: evidence for a developmental cascade. *Psychological Science*, *7*, 237 – 241.

Fuson, K. C. (1982). An anlysis of the counting –on solution procedure in addition. In T. P. Carpenter, J. M. Moser, & T. A. Romberg (Eds.) *Addition and subtraction: A cognitive perspective* (pp. 67 – 81). Hillsdale, NJ: Erlbaum.

Galaburda A, & Kemper T. (1979). Cytoarchitectonic abnormalities in developmental dyslexia: a case study. *Annals of Neurology*, *6*, 94 – 100.

Galaburda, A., & Livingstone, M. (1993). Evidence for a magnocellular defect in developmental dyslexia. *Annals of the New York Academy of Science, 682*, 70-82.

Gallistel, C. R., & Gelman, R. (1992). Preverbal and verbal counting and computation. *Cognition, 44*, 43 – 74.

Gathercole, S.E., & Baddeley, A. D., (1993). *Working memory and language*. New York, NY: Psychology Press.

Geary, D.C., Widaman, K.F., Little, T.D., & Cormier, P. (1987). Cognitive addition: Comparison of learning disabled and academically normal elementary school children. *Cognitive Development*, *2*, 249-269.

Geary, D. C. (1991). Cognitive Addition: A short longitudinal study of strategy choice and speed of processing differences in normal and mathematically disabled children. *Developmental Psychology*, *27*, 787-797.

Geary, D.C., Brown, S.C., & Samaranayake, V.A. (1991). Cognitive addition: a short longitudinal study of strategy choice and speed of processing difference in normal and mathematically disabled children. *Developmental Psychology, 27*(5), 787 – 797.

Geary, D. C., & Wiley, J. G. (1991). Cognitive addition: Strategy choice and speed-of-processing differences in young and elderly adults. *Psychology and Aging*, *6*, 474-483.

Geary, D. C., Bow-Thomas, C. C., & Yao, Y. (1992). Counting knowledge and skill in cognitive addition: A comparison of normal and mathematically disabled children. *Journal of Experimental Child Psychology*, *54*, 372-391.

Geary, D.C. (1993). Mathematical disabilities: Cognitive, neuropsychological, and genetic components. *Psychological Bulletin, 114*, 345-362.

Geary, D. C., Hoard, M. K., & Hamson, C. O. (1999). Numerical and arithmetical cognition: Patterns of functions and deficits in children at risk for a mathematical disability. *Journal of Experimental Child Psychology*, *74*, 213-239.

Geary, D. C., Saults, S. J., Liu, F., & Hoard, M. K. (2000). Sex differences in spatial cognition, computational fluency, and arithmetical reasoning. *Journal of Experimental Child Psychology*, *77,* 337-353.

Geary, D. C., Hamson, C. O., & Hoard, M. K. (2000). Numerical and arithmetical cognition: A longitudinal study of process and concept deficits in children with learning disability. *Journal of Experimental Child Psychology*, *77,* 236-263.

Geary, D. C. (2001). Darwinism, schooling, and mathematics: How an understanding of evolution can inform instructional practices. In T. Loveless (Ed.), *Curriculum wars: Alternative approaches to reading and mathematics* (pp. 85-107). Cambridge, MA: Harvard University Press.

Geary, D. C., & Hoard, M. K. (2001). Numerical and arithmetical deficits in learning-disabled children: Relation to dyscalculia and dyslexia. *Aphasiology*, *15*, 635-647.

Geary, D. C., & Hoard, M. K. (2002). Learning disabilities in basic mathematics: Deficits in memory and cognition. In J. M. Royer (Ed.), *Mathematical cognition* (pp. 93-115). Greenwich, CT: Information Age Publishing.

Geary, D.C. (2004). Mathematics and learning disabilities. *Journal of Learning Disabilities*, *37*, 4-15.

Geary, D. C., Hoard, M. K., Byrd-Craven, J., & DeSoto M. C. (2004). Strategy choices in simple and complex addition: Contributions of working memory and counting knowledge for children with mathematical disability. *Journal of Experimental Child Psychology*, *88,* 121 – 151.

Geary, D.C., Hoard, M.K., Nugent L. & Byrd-Craven, J. (2007) Strategy use, long-term memory and working memory capacity. In D. B. Berch & M.M. Mazzocco (Eds) *Why is math so hard for some children? The nature and origins of mathematical learning difficulties and disabilities* (pp.83-105). Baltimore, MD: Paul H. Brooklet.

Geary, D. C. (2011). Consequences, characteristics, and causes of poor mathematics achievement and mathematical learning disabilities. *Journal of Developmental and Behavioral Pediatrics, 32*, 250-263.

Geiger, G. and Lettvin, J. Y. (1987). Peripheral Vison on Persons with Dyslexia. *New England Journal of Medicine, 316,* 1238 – 1243.

Gersten, R. and Chard, D. J. (2001). Number sense: Rethinking arithmetic instruction for students with mathematical disabilities. Retrieved from http://www.Idonline.org/article/5838/

Griffin, S. (2004). Teaching number sense. *Educational Leadership*, *61*, 39-42.

Groen, G.J., & Parkman, J.M. (1972).A chronometric analysis of simple arithmetic. *Psychological Review*, *79*, 329 – 343.

Grossen, Benita (1997). A synthesis of research on reading from the national institute of child health and human development. Retrieved from http://www.nrrf.org/synthesis_research.htm.

Habib, M. (2000). The neurological basis of developmental dyslexia: An overview and working hypothesis. *Brain*, *123*, 2373 – 2399.

Hammarrenger, B., Lepore, F., Lippe, S., Labrosse, M., Guillemot, J. P., & Roy M. S. (2003). Magnocellular and parvocellular developmental course in infants during the first year of life. *Documenta Ophthalmologica*, *107*, 225-233.

Hartnedy, S. L., Mozzoni, M. P., & Fahoum, Y. (2005). The effects of fluency training on math and reading skills in neuropsychiatric diagnosis children: A multiple baseline design. *Behavioral Interventions*, *15,* 261-268.

Hill, R. & Lovegrove, W. (1993). One word at a time: A solution to the visual deficit in SRDs? In Wright, S. F. & Groner, R. (Eds.), *Studies in visual information processing: Facets of dyslexia and its remediation*. London: North-Holland.

Hittmair-Delazer, M., Semenza C., & Denes, G. (1994). Concepts and facts in calculation. *Brain*, *117*, 715 – 728.

Horn, J. & Noll, J. (1997). Human cognitive capabilities: Gf-Gc theory. In D.P. Flanagan, J.L. Genshaft, & P.L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests and issues* (pp. 53-91). New York: Guilford.

Hudson, R.F., High, L., & Al Otaiba, S. (2007). Dyslexia and the brain: What does current research tell us? *The Reading Teacher*, *60*, 506-515.

Hulslander, J., Talcott, J., Witton, C., DeFries, J., Pennington, B., Wadsworth, S., Willcutt, E., & Olson, R., (2004). Sensory processing, reading, IQ and attention. *Journal of Experimental Child Psychology, 88,* 274-295.

Hutzler, F., Kronbichler, M., Jacobs, A. M., & Wimmer, H. (2006). Perhaps correlational but not causal: No effect of dyslexic readers' magnocellular system on their eye movements during reading. *Neuropsychologia, 44*, 637-648.

Jonides, J. Lacey, S.C., & Nee, D.E. (2005). Process of working memory in mind and brain. *Current Directions on Psychological Science*, *14*, 2-5.

Jordan, N. C. & Montani, T.O. (1997). Cognitive arithmetic and problem solving: A comparison of children with specific and general mathematics difficulties. *Journal of Learning Disabilities*, *30*, 624 - 634.

Jordan, N.C., Hanich, L.B., & Kaplan, D. (2003). A longitudinal study of mathematical competencies in children with specific mathematics difficulties versus children with comorbid mathematics and reading difficulties. *Child Development*, *74*, 834 – 850.

Jordan, N. C., Kaplan, D., Nabors, O. L., & Locuniak, M. (2006). Number sense growth in kindergarten: a longitudinal investigation of childeren at risk for mathematics difficulties. *Child Development*, *77*(1), 153 – 75.

Kail, R. (1992). Processing speed, speech rate, and memory. *Development Review*, *28,* 899 – 904.

Kail, R. (1997) Phonological skill and articulation time independently contribute to the development of memory span. *Journal of Experimental Child Psychology*, *67*, 57-68.

Kail, R., & Hall, L.K. (2001). Distinguishing short-term memory from working memory. *Memory & Cognition, 29,* 1-9.

Kaufman, A. S., & Kaufman, N. L. (2004). *Kaufman Brief Intelligence Test (2nd ed.).* Minneapolis, MN: Pearson.

Kaufman, A.S. (2009). *IQ Testing 101*, New York: Springer Publishing Company.

Kosc, Ladislav (1974). Developmental dyscalculia. *Journal of Learning Disabilities, 7*, 159-62.

Kosc, L. (1974). Developmental dyscalculia. *Journal of Learning Disabilities, 7*, 164-177.

Kyllonen, P.C. & Christal, R.E. (1990). Reasoning Abililty is (little more than) working memory capacity. *Intelligence, 14*, 389 – 433.

Landerl, K., Bevan, A., and Butterworth, B. (2004). Developmental dyscalculia and basic numerical capacities: A study of 8 – 9 year students. *Cognition*, *93*, 99 – 125.

Lane, David (2013). Online Statistics Education: A Multimedia Course of Study. Retrieved from http://onlinestatbook.com/2/index.html.

LaBerge, D. & Samuels, S. (1974). Toward a theory of automatic information processing in reading. *Cognitive Psychology, 6*, 293-323.

Lipton, J.S., & Spelke, E.S. (2003). Origin of number sense: Large-number discrimination in human infants. *Psychological Science, 14*, 369-401.

Livingstone MS, Rosen GD, Drislane FW, & Galaburda A. M. (1991). Physiological and anatomical evidence for a magnocellular defect in developmental dyslexia. *Proceedings of the National Academy of Sciences of the United States of America, 88*, 7943-7947.

Lovegrove, W.J., Bowling, A., Badcock, D., & Blackwood, M. (1980). Specific reading disability: Differences in contrast sensitivity as a function of spatial frequency. *Science, 210*, 439-440.

Loveless, T. “Trends in Math Achievement: The Importance of Basic Skills.” Presentation at the Mathematics Summit, Washington, DC: February 6, 2003.Makita K. (1968). The rarity of reading disability in Japanese children. *American Journal of Orthopsychiatry, 38*, 599–614.

Mabbott, D. J., & Busanz, J. (2008). Computational skills, working memory, and conceptual knowledge in older children with mathematics learning disabilities. *Journal of Learning Disabilities*, *41*, 15 – 28.

Makita K. (1968). The rarity of reading disability in Japanese children. *American Journal of Orthopsychiatry*, *38*, 599–614.

Mangen, R. What is processing speed? Retrieved from http://www.forestheightslodge.org/what-is-processing-speed--dr-rich-mangen.html

Maunsell, J.H.R., & Gibson, J.R. (1992) Visual response latencies in striate cortex of the macaque monkey. *Journal of Neurophysiology*, *68*, 1332-1344.

Martin, Thomas A. & Bush, Shane S. (2008). Assessment tools and research methods for human information processing speed. In John DeLuca and Jessica H. Kalmar (Ed.) Information Processing Speed in Clinical Populations (pp. 29 – 51). New York, NY: Taylor and Francis.

Mazzocco, M. M. M. & Myers G. F. (2003). Complexities in identifying and defining mathematics, learning disability in the primary school-age years. *Annals of Dyslexia*, *53*, 218-253.

Mazzocco, M.M.M. (2007). Defining and differentiating mathematical learning disabilities and difficulties. In Berch, D. B. & Mazzocco, M. M. M. (Eds.). *Why is math so hard for some children? The nature and origins of mathematical learning difficulties and disabilities*. (pp. 29-48). Baltimore, MD: Paul H. Brookes Publishing.

McLean, J. F., & Hitch, G. J. (1999). Working memory impairments in children with specific arithmetic learning difficulties. *Journal of Experimental Child Psychology*, *74*, 240-260.

Mercer, C. D., Jordan, L., Allsopp, D. H., & Mercer, A. R. (1996). Learning disabilities definitions and criteria used by state education departments. *Journal of Learning Disabilities, 19*, 217–232.

Miller, S. P., & Mercer, C.D. (1997). Educational aspects of mathematics disorders. *Journal of Learning Disabilities, 30*, 47-56.

Milne, E., Swettenham, J., Hansen, P., Campbell, R., Jeffries, H., & Plaisted, K. (2002). High motion coherence thresholds in children with autism. *Journal of Child Psychology and Psychiatry, 43*, 255 – 263.

Milne, E., White, S., Campbell, R., Swettenham, J., Hansen, P., & Ramus, F. (2006). Motion and form coherence detection in autistic spectrum disorder: Relationship to motor control and 2:4 digit ratio. *Journal of Autism and Developmental Disorders, 36*, 225–237.

Munro, J. D. (2003). Dyscalculia: A unifying concept in understanding mathematics learning disabilities. *Australian Journal of Learning Disabilities, 8*, 4. Retrieved from http://www.edfac.unimelb.edu.au/eldi/selage/documents/MLDR-Dyscalculiatypes.pdf

National Association for the Education of Young Children, Position Paper (2009). Where we stand on early learning standards. As retrieved from http://www.naeyc.org/files/naeyc/file/positions/earlyLearningStandards.pdf

National Council of Teachers of Mathematics, Key Messages (2004). Retrieved from: http://www.nctm.org/uploadedFiles/Research,_Issues_and_News-Section_Navigation/Be_an_Advoate/key_msg.pdf.

National Mathematics Advisory Panel. (2008). Foundations for Success: The Final Report of the National Mathematics Advisory Panel. U.S. Department of Education: Washington, DC.

Nicolson, R. (1998). Developmental dyslexia: Past, Present and Future. *Dyslexia, 2,* 1996.

Nieder, A., Freedman, D. J., & Miller, E. K. (2002). Representation of the quantity of visual items in the primate prefrontal cortex, *Science*, *297*, 1708–1711,

Noel, M.P., (2000). Developmental Dyscalculia: State of the art. In M. Meseti and X. Seron *Neuropsycholology of Mathematics and Numeracy Difficulties*. Marseille, France: Solal, 59-84.

Norton, E.S. & Wolf, M.. (2012). Rapid autonmatized naming (RAN) and reading fluency: Implications for understanding and treatment of reading disabilities. *Annual Review of Psychology*, *63*, 427 – 452.

O'Hearn, K, & Luna, B. (2009). Mathematical skills in Williams Syndrome: Insight into the importance of underlying representations. Developmental Disabilities, *15*, 11 – 20.

Orton,S. T. (1925). Word-blindness in school children. *Archives of Neurology and Psychiatry, 14*, 582-615.

Pavlidis, G. T. (1981). Do eye movements hold the key to dyslexia? *Neuropsychologia*, *19*, 57-64.

Pellegrino, J.W., & Goldman, S.R. (1987). Information processing and elementary mathematics. *Journal of Learning Disabilities*, *20*, 23-32.

Pikulski, J., & Chard, D. (2005). Fluency: Bridge between decoding and reading comprehension. *International Reading Association*, *58*, 510-519.

Poncy, B. (2009). Developing math automaticity using a classwide fluency building procedure for middle school students: a preliminary study. *Psychology in the Schools*, *46*, 526 – 538.

ProximityOne (2014). Retrieved from: http://proximityone.com/sddep.htm#mo.

Ramus, F., Rosen, S., Daykin, S., Day, B., Castellote, J., White, S., & Frith, U. (2003). Theories of developmental dyslexia: Insights for a multiple case study of dyslexic adults. *Brain, 126*, 841-865.

Rivera-Batiz, F. L. (1992). Quantitative literacy and the likelihood of employment among young adults in the United States. *Journal of Human Resources, 27*, 313-328.

Rosselli, M., Matute, E., Pinto, N., & Ardila, A. (2006). Memory abilities in children with subtypes of dyscalculia. *Developmental Neuropsychology, 30*, 801-818.

Rourke, B.P. (1993). Arithmetic disabilities specific and otherwise: A neuropsychological perspective. *Journal of Learning Disabilities*, *26*, 214 – 226.

Royer, J.M., Tronsky, L.N., Chan, Y., Jackson, S.J., & Marchant, H. (1999). Math fact retrieval as the cognitive mechanism underlying gender differences in math test performance. *Contemporary Educational Psychology, 24*, 181–266.

Salthouse, T.A. (1996b). The processing speed theory of adult age difference in cognition. *Psychological Review*, *103*, 403 – 428.

Sandhu, Inderbir Kaur, Ph.D. (2001). The Wechsler Intelligence Scale for Children – Fourth Edition. As retrieved from: http://www.brainy-child.com/expert/WISC_IV.shtml

Siegler, R.S. (1996). *Emerging minds: the process of change in children's thinking*. New York: Oxford University Press.

Schneider, J., & McGrew, K. (2013). The Cattell-Horn-Carroll (CHC) model of intelligence v2.2: A visual tour and summary. Institute for Applied Psychometrics, as retrieved from http://www.iapsych.com/chcv2.pdf.

Schrank, F.A., McGrew, K.S., & Woodcock, R.W. (2001). *Technical Abstract*: *Woodcock Johnson III Assessment Service Bulletin* (No. 2). Itasca, IL: Riverside Publishing.

Shalev, R. S., & Gross-Tsur, V. (1993). Developmental dyscalculia and medical assessment. *Journal of Learning Disabilities*, *26*, 134-137.

Shalev, R. S., & Gross-Tsur, V. (2001). Developmental dyscalculia. *Pediatric Neurology*, *24*, 337-342.

Shaywitz, S. (1996). Dyslexia. *Scientific American*, 275(5), 98 – 104.

Shaywitz, B. A., Shaywitz, S. E., Blachman, B. A., Pugh, K. R., Fulbright, R. K., & Skudlarski, P. (2004). Development of left occipitotemporal systems for skilled reading in children after a phonologically based intervention. *Biological Psychiatry*, *55*, 926–933.

Shaywitz, S. E., Shaywitz, B. A., Fulbright, R. K., Skudlarski, P., Mencl, W. E., & Constable, R. T. (2003). Neural systems for compensation and persistence: Young adult outcome of childhood reading disability. *Biological Psychiatry*, *54*, 25–33.

Shaywitz, S., Morris, R., & Shaywitz, B. (2008). The education of dyslexic children from childhood to young adulthood. *Annual Review of Psychology*, *59*, 51-475.

Shepard, L.A. (1994). The challenges of assessing young children appropriately. Phi Delta Kappan,

Siegler, R.S. & Shrager, J. (1984). Strategy choices in addition and subrraction: How dochildren know what to do? Editor C. Sophian, *The origins of cognitive skills* (pp. 229 – 293). Hillsdale, NJ: Erlbaum.

Sigmundsson, H., Anholt, S. K., & Talcott, J. B. (2010). Are poor mathematics skills associated with visual deficits in temporal processing? *Neuroscience Letters*, *469*, 248–250.

Simos, P.G., Kanatsouli, K., Fletcher, J.M., Sarkari, S., Juranck, J., Cirino, P., & Papanicolaou, A. (2008). Aberrant spatiotemporal activation profiles associated with math difficulties in children: A magnetic source imaging study. *Neuropsychology*, *22*, 571-584.

Silver, C.H., Pennett, H.D., Black, J.L., Fair, G.W. & Balise, R.R. (1999). Stability of arithmetic disability subtypes. *Journal of Learning Disabilities*, *32*, 108-119.

Skottun, B. & Skoyles, J.R. (2006). Is coherent motion an appropriate test for magnocellular sensitivity? *Brain and Cognition*, *61*, 172-180.

Skottun, B. & Skoyles J. R. (2008). Coherent motion, magnocellular sensitivity and the causation of dyslexia. *International Journal of Neuroscience*, *118*, 185 – 190.

Sloan, H.A., Hansen, M.A., Shelley-Tremblay, J., & Ficarra, A. (2003). Coherent motion threshold measurements for M-cell deficit differ for above- and below-average readers. *Optometry*, *74*, 727-733.

Snowden, R., Thompson P., & Troscianko, T. (2006). *Basic Vision: An introduction to visual perception*. New York, NY: Oxford University Press.

Sperling, A. J., Lu, Z. L., Manis, F.R., & Seidenberg, M.S (2003). Selective magnocellular deficits in dyslexia: a “phantom contour” study. *Neuropsychologia*, *41*, 1422 – 1429.

Sperling, A. J., Lu, Z. L., Manis, F.R., & Seidenberg, M.S. (2005). Deficits in perceptual noise exclusion in developmental dyslexia. *Nature Neuroscience*, *8*, 862 – 863.

Starkweather, Jon (2010) Homogeneity of Variances. Retrieved from: http://www.unt.edu/rss/class/Jon/Benchmarks/Levene_JDS_Mar2010.pdf.

State of Missouri Guidance for Identification of Specific Learning Disability, (2008). Retrieved from http://dese.mo.gov/3tieredmodels/rti/documents/RtIGuidance08.pdf.

Stein J. & Walsh V. (1997). To see but not to read: the magnocellular theory of dyslexia. *Trends Neuroscience*, *20*, 147-152.

Stein, J., & Fowler, M. S. (1993). Unstable binocular control in dyslexic children. Journal of Research in Reading, *16*, 30-45.

Stein J, & Walsh, V. (1997). To see but not to read: the magnocellular theory of dyslexia. *Trends Neuroscience* , *20*, 147–52.

Stein, J. and Talcott, J. (1999). Impaired neuronal timing in developmental dyslexia – the magnocellular hypothesis. *Dyslexia*, *5*, 59-77.

Stein, J. (2001). The magnocellular theory of developmental dyslexia. *Dyslexia*, *7*, 12-36.

Stoodley, C.J., Talcott, J.B., Carter, E. J., Witton, C., & Stein, J. (2000). Selective defixits of vibrotactile sensitivity in dyslexic readers. *Neuroscience Letters*, *295*, 13-16.

Sutaria, S. D. (1985). *Specific learning disabilities: Nature and needs*. Springfield, IL: Charles C. Thomas, 359.

Swanson, H.L., & Jerman, O. (2007). The influence of working memory on reading growth in subgroups of children with reading disabilities. *Journal of Experimental Child Psychology*, *96*, 249-283.

Tabachnick, B.G. and Fidell, L. S. (2007). *Using Multivariate Statistics (5th Ed.)*, Boston, MA: Pearson, Allyn and Bacon.

Talcott, J. B., Hansen, P. C, Assoku, E. L, & Stein, J. F. (2000). Visual motion sensitivity in dyslexia: evidence for temporal and energy integration deficits. *Neuropsychologia*, *38*(7), 935-943.

Talcott, J. B., Witton, C., McLean, M.F., Hansen, P.C., Rees, A., Green, & Stein, J. (2000). Dynamic sensory sensitivity and children's word decoding skills. *PNAS*, *97*, 2952-2957.

Talcott, J. B., Witton, C., Hebb, G.S., Stoodley C.J., Westwood, E. A., France, S.J., & Stein, J. (2002). On the relationship between dynamic visual and auditory processing and literacy skills; results from a large primary-school study. *Dyslexia, 8*, 204-225.

Thompson, J., Shillcock, R.C., & McDonald, S.A. (2003). The Role of the Magnocellular Pathway in Visual Word Recognition. Retrieved from http://amlap.psy.gla.ac.uk/programme/posters2/node24.html

Torgesen, J.K. (1984). Instructional Use of Microcomputers with Elementary Aged Mildly Handicapped Children. *Microcomputers and Exceptional Children, 1*, 37-48.

U.S. Department of Education (2004).. *28th Annual Report to Congress on the Implementation of the Individuals with Disabilities Education Act. (2004).* Retrieved from http://www2.ed.gov/about/reports/annual/osep/2006/parts-b-c/28th-vol-1.pdf

Vidyasagar, T. R. (2004). Neural underpinnings of dyslexia as a disorder of visuo-spatial attention. *Clinical Experimental Optometry, 87*, 4-10.

Vukovic, R. & Siegel, L. (2010). Academic and cognitive characteristics of persistent mathematics difficulty from first through fourth grade. *Learning Disabilities Research & Practice*, *25*(1), 25 – 38.

Wechsler, David (2003). Manual for the Wechsler Intelligence Scale for Children – Fourth Edition. San Antonio, TX: The Psychological Corporation.

Weiss, L.G., Saklofske, D. H., Prititera, A., & Holdnack, J.A. (2006). *WISC-IV: Advanced clinical interpretation.* Burlington, MA: Academic Press.

Weiss, L. G., and Gabel, A. D. (2008). WISC IV: Using the cognitive proficiency index in psychoeducational assessment. Technical Report #6, Pearson Education, Inc., as retrieved from: http://www.pearsonassessments.com/NR/rdonlyres/E15367FE-D287-46B4-989A-609160D94DA8/0/WISCIVTechReport6.pdf

Whitaker, H. A./, Habiger, J., & Ivers, R. (1985). Acalculia from a lenticular-caudate lesion. *Neurology, 35*, 161.

Whitehurst, G. (2003, February 6). IES Director's presentation at the Mathematics Summit, Washington, DC. Retrieved from http://www.cssu.org/cms/lib5/vt01000775/centricity/domain/132/fluency_rationale.pdf

Willows, D. M., Kruk, R. S., & Corcos, E., (1993). Visual processes in reading and reading disabilities. London: Lawrence Erlbaum.

Wilson, A. (n.d.) Dyscalculia primer and resource guide, retrieved from http://www.oecd.org/document/8/0,3746,en_2649_35845581_34495560_1_1_1_1,00.html

Wilson, K.M., & Swanson, H.L. (2001). Are mathematics disabilities due to a domain-general or a domain-specific working memory deficit? *Journal of Learning Disabilities*, *34*, 237-248.

Wimmer, H. (1993). Characteristics of developmental dyslexia in a regular writing system. Applied Psycholinguistics, *14*(1), 1 – 33.

Woodcock, Richard W., McGrew,Kevin S., Mather, Nancy, 2001. Woodcock-Johnson Tests of Achievement (WJ III). Riverside Publishing. Retrieved from http://alpha.fdu.edu/psychology/woodcock_ach_descrip.htm

Woodward, J. & Baxter, J. (1997). The effects of an innovative approach to mathematics on academically low-achieving students in inclusive settings. *Focus on Exceptional Children, 63*, 373-388.

Uu, F., Spelke, E. S., & Goddard, S. (2005). Number sense in human infants. *Developmental Science*, *8*, 88 – 101.

Ziegler, J.C., and Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin, 131*, 3 – 29.

Zheng, X., Swanson, H. L., & Marcoulides, G. (2011). Working memory components as predictors of children's mathematical work problem solving. *Journal of Experimental Child Psychology*, *110*, 481 – 498.

Appendix A
Guidelines followed for Assessment

1. Obtain district permission

2. Meet with the Director of Special Education to discuss the study. She will contact the teachers and have the teachers select students that meet the criteria mentioned in the study.

3. Meet with individual Special Education Teachers (SPED). Prior to the meeting, SPED teachers will contact parents asking them if I can speak to their child about the study.

4. Meet with the students and discuss the study and answer any questions. A letter will be sent home to the parent discussing the study. Meet with the building principal of each school to inform them of what I will be doing in their school.

5. Arrange date and time for the study.

6. Go to the school and begin testing. Each student will be individually brought to the testing site.

7. Administer an informal vision and screening

8. Administer the math fluency subtest (3 mins.)

9. then math calculation subtest

10. Conduct the Coherent Motion Test (trial test first)

11. Administer the Processing Speed Index (Coding – 2 mins and then Symbol Search – 2 mins.

12. Thank student and give them the gift card

13. Score results

14. Mail results to the parents

Appendix B: Child Consent

Division of Teaching and Learning

College of Education
One University Blvd.
St. Louis, Missouri 63121-4499
Telephone: 314-275-7592
E-mail: larosa_thomas@yahoo.com

Assent to Participate in Research Activities (Minors)

The Impact of Visual Processing on Math Fluency and Processing Speed

1. My name is Tom LaRosa; most children call me Mr. Tom.

2. I am asking you to take part in a research study because we are trying to learn more about how you do math and how well you see.

3. If you agree to be in this study you will be asked to take three short tests. The tests will not be graded or part of your grades on your report card and they will NOT be given to your teacher. All of the tests will be done with me at your school. Before any tests, you will be given a short test to make sure you can see what you are reading and writing.

- The first test will be done on a laptop computer. You will be asked to look at dots moving across the screen.
- The next test is on math facts. The math facts test will ask you to answer math facts using plus, take away, and times, going as fast as you can. It is OK if you do not know all of your times tables or if you do not know all of your math facts when you do this. Just do the best you can.
- The last tests are two short tests for speed. One asks you to fill in some blank squares on a page with shapes that are on the top of the page. The other test asks you to look at rows of shapes. Both tests only take two minutes to do.

4. Being in this study should not harm you in any way. If you feel bad about some of your answers please come and talk to me.

5. Being part of this study may teach you something about how you learn math. You will receive a five dollar debit card for your time.

6. If you don't want to be in this study, you don't have to participate.

7. You can ask any questions that you have about the study. If you have a question later that you didn't think of now, you can call me at 314-275-7592.

8. Signing your name at the bottom means that you agree to be in this study. You will be given a copy of this form after you have signed it.

________________________ ____ ________________________

Participant's Signature Date Participant's Printed Name

_______________ __________________

Participant's Age Grade in School

Appendix C: Informed Parental Consent

Division of Teaching and Learning

College of Education
One University Blvd.
St. Louis, Missouri 63121-4499
Email: larosa_thomas@yahoo.com

Informed Consent for Child Participation in Research Activities

The Impact of Visual Processing on Math Fluency and Processing Speed

Participant ________________________________ HSC Approval Number: 241548-6

Principal Investigator Thomas LaRosa, Ed. S. P.I.'s Phone Number 314-275-7592

Your child is invited to participate in a research study conducted by Tom LaRosa, under Dr. Patricia Kopetz at the University of Missouri – St. Louis. Students with and without learning disabilities will be involved in the study. The purpose of this research is to investigate an association between the brain understanding what it is seeing and math ability. The study will also investigate the existence of a relationship between speed and math calculation.

Your child's participation will involve:

- Prior to any testing, all students in the study will be given an informal vision screening by the examiner, Tom LaRosa. This informal screening will check for vision accuracy. Students with normal vision [20/20], both near and far-point, with or without glasses, can be included in this study.

- The Coherent Motion Threshold measure the detection of motion. This test will be done on a laptop computer. The student will be asked to look at dots moving across the screen.

- Math fluency involves the ability to respond to basic math facts. This measure involves the child answering basic math facts in addition, subtraction, and multiplication during a 3 - minute time period. The other math test is a math calculation test which involves the child solving addition, subtraction, multiplication and division. The child is asked to do as many as they can until they miss 6 in a row.

- Processing speed involves two short tests. On the first test the child is asked to copy symbols from a key on top of the page to an empty square that coincides with a number (each number has a specific symbol) within a two minute time period. On the second subtest, the child is asked to scans rows of symbols to determine if any symbols at the beginning of each line match the symbols in the rest of the line. The subject has a two minute time period to complete the task.

- Those students without a learning disability will be asked to do a 45 minute intelligence test.

- All testing will be completed at your child's school and will take approximately 60 to 90 minutes. I will take your child out of the classroom to a separate room to do the testing.
  Approximately 36 children may be participants in this research within the area.

  There are no anticipated risks to your child associated with this research.

The possible benefits to you and your child from participating in this research will be a summary of all of the testing done on your child, which will be mailed to you. This may provide a better understanding of your child's unique needs. Children participating in the study will receive ten dollars or a ten dollar debit card as an appreciation for their time.

Your child's participation is voluntary and you may choose not to let your child participate in this research study. You may withdraw your consent for your child's participation at any time. Your child may choose not to answer any questions that he/she does not want to answer. You and your child will NOT be penalized in any way should you choose not to let your child participate or if you choose to withdraw your child. No results will be given to the teacher or principal.

I will do everything we can to protect your child's privacy. As part of this effort, your child's identity will not be revealed in any publication or presentation that may result from this study. In rare instances, a researcher's study must undergo an audit or program evaluation by an oversight agency (such as the Office for Human Research Protection). That agency would be required to maintain the confidentiality of your child's data.

If you have any questions or concerns regarding this study, or if any problems arise, you may call the Investigator, Tom LaRosa: 314 –275–7592, or his Faculty Advisor, Dr. Patricia Kopetz at 314-516-4885. You may also ask questions or state concerns regarding your child's rights as a research participant to the UMSL Office of Research Administration, at 314- 516-5897.

I have read this consent form and have been given the opportunity to ask questions. I will also be given a copy of this consent form for my records. I consent to my child's participation in the research described above.

____ ____
Parent's/Guardian's Signature Date Parent's/Guardian's Printed Name

____
Child's Printed Name

____ ____
Signature of Investigator or Designee Date Investigator/Designee Printed Name

Appendix D: Written Report

NAME: **GRADE:**

DATE OF BIRTH: **AGE:** years

Evaluator: Thomas J. LaRosa, Ed. S. School Psychologist

Date of Evaluation:

NAME was a pleasure to test. He/She arrived for the testing in a pleasant manner and was cooperative during all of the assessments.

Woodcock-Johnson III

Current level of academic Math Calculation and Fluency was measured on the Woodcock –Johnson Tests of Achievement III (WJ-III) on DATE. The test has a mean of 100 and a standard deviation of 15. The WJ-III is designed to measure scholastic achievement in reading, math and written expression. It requires written and oral responses and can be utilized with individuals age three through adulthood. Administration of this instrument resulted in the following:

Calculation is a test of math achievement measuring the ability to perform mathematical computations. The initial items in Calculation require the individual to write single numbers. The remaining items require the person to perform addition, subtraction, multiplication, division, and combinations of these basic operations. The mathematical calculations are presented in a traditional problem format in the Subject Response Booklet, the subject is not required to make any decisions about what operations to use or what data to include. NAME fell in the average (90 – 109) range in his/her ability to perform math calculations (standard score 101, suggesting he/she performed better than 52% of his/her peers)

Math Fluency is the ability to quickly solve basic math (addition, subtraction, multiplication) facts. This subtest test is a three minute timed test. NAME was able to correctly respond to # facts, placing him/her in the #%ile, and a standard score of 92. This places him/her in the average (90 – 109) range.

WISC IV: Processing Speed Index

Wechsler Intelligence Scale for Children – Fourth Edition (WISC-IV). The test has a mean of 100, standard deviation of 15. The composite scores have a mean of 100 with a standard deviation of 15. The Processing Speed Index of the WISC IV was administered. The Processing Speed Index score results from statistical analysis of the child's performance on the Coding and Symbol Search subtests. Each subtest uses scaled scores instead of standard scores. Each subtest has a possible of a scaled score of 19, with 10 being average.

The creator of the WISC IV states "the Processing Speed Index provides a measure of the child's ability to quickly and correctly scan, sequence, or discriminate simple visual information." NAME obtained a Processing Speed score of --, placing him/her in the --%ile. He/She scored higher than approximately _ out of 100 children his/her age on tasks requiring him/her to quickly scan symbols and make judgments about them. NAME's ability in processing simple or routine visual material without making errors is in the Average (90 –

109) range when compared to his/her peers. NAME received a scaled score of _ on the Symbol Search subtest and a scaled score of _ on Coding.

It is important to realize that Coding is not just a measure of processing speed. It is a measure that includes associative learning, and that has been found to be related to sound (phoneme)-symbol (grapheme) association, or the alphabetic principle, which is which are important to the reading process.

Kaufman Brief Intelligence Test

The Kaufman Brief Intelligence Test (K-BIT 2) is a quick, easily scored, cognitive assessment instrument to be administered to children (beginning with age 4:0 to adults age 80:11).

Subscales	**Standard Score (IQ)**	**Percentile**
Verbal		
Nonverbal		
Composite		

The difference between his verbal and nonverbal scores is / is not statistically significant. This suggests that NAME's verbal and nonverbal skills are evenly developed and that Haley may express his/her intelligence using either mode. This suggests that NAME's verbal/nonverbal skills are more highly developed at this time than his/her verbal/nonverbal skills. NAME's Verbal score of _ and his/her Nonverbal score of _ both fall within the Average (85 – 115) range Above Average (116 – 130) range Upper Extreme (≥131) range of intelligence. His/Her Composite score of __ falls within the Upper Extreme (≥131) range Above Average (116 – 130) range Average (85 – 114) range of intelligence.

NAME's Composite score (composite score is the combination of the verbal and nonverbal scores) of __ falls within the Average (85 – 115) range of intelligence. Upper Extreme (≥131) range Above Average (116 – 130) range

____

Thomas J. LaRosa, Ed. S.

School Psychologist

APPENDIX E
Definition of Terms

Dyscalculia: Kosc (1974) called it a difficulty in mathematical performance resulting from impairment to those parts of the brain that are involved in mathematical processing, without a concurrent impairment in general mental function. The DSM-IV (Diagnostic and Statistical Manual of Mental Disorders, 4th Ed, American Psychiatric Association) includes the diagnosis 315.1 "Mathematics Disorder", and in the United States there is an educational definition of "Mathematical Disabilities" linked to the legal definition of learning disabilities given in Public Law 94-142. (Wilson, n.d.)

Dyslexia: "Dyslexia is a neurologically-based, often familial, disorder which interferes with the acquisition and processing of language. Varying in degrees of severity, it is manifested by difficulties in receptive and expressive language, including phonological processing, in reading, writing, spelling, handwriting, and sometimes in arithmetic." Revised definition from the International Dyslexia Association (n.d.).

Coherent Motion Threshold : A random dot kinemetogram which is presented to the subject on a computer under low luminance conditions. It provides an accurate measure of motion sensitivity and is considered the most appropriate method to test for impaired M pathway. (Cornelissen, Hansen, Gilchrist, Cormack, Frankish, 1998)

Lateral Geniculate Nucleus (LGN): Acts as a relay point for visual information from the retina of the eye. It consists of six layers. Layers 1 & 2 contain the magnocellular layers and layers 3, 4, 5, and 6 are known as the parvocellular layers. (Snowden, Thompson, & Troscianko, 2006).

Magnocellular Pathway (M-path): Begins in the retinal ganglion cells and extends to the visual cortex by way of the lateral geniculate nucleus (LGN). The M-path is comprised of the M-cell stream, which is sensitive to visual motion and flicker. Solan, H. (2006).

***Mathematics Disorder* (MD):** May be referred to as developmental arithmetic disorder, or dyscalculia. The DSM IV–R defines mathematics disorder as "Mathematic ability that falls substantially below that expected for the individual's chronological age, measured intelligence, and age-appropriate education (Criterion A)." It states, "The difficulties in mathematics significantly interfere with academic achievement or with activities of daily living that require mathematical skills (Criterion B). (American Psychiatric Association, 2000, p.54).

***Orthography*:** The visual form of words, the shape of letters, their order in words, and common spelling patterns. (Stein, 2001).

Parvocellular Pathway (P-path): Begins in the retinal ganglion cells and extends to the visual cortex by way of the lateral geniculate nucleus (LGN). The P-path is comprised of the P-cell stream which is sensitive to light and color. Solan, H et. al. (2006)

***Processing Speed Index*:** Composed of two subtests, Coding and Symbol Search, on the Wechsler Intelligence Scale for Children, 4th edition that measures of the rapidity with which an individual can process simple or routine information without making errors. (Coalson & Weiss, 2002). It is the speed the brain can handle information.

Processing Speed: measures children's abilities to focus attention and quickly scan, discriminate between, and sequentially order visual information. (Coalson & Weiss, 2002)

Specific Learning Disability (SLD): The Individuals with Disabilities Education Act (IDEA, 1997) states that those children who have a disability in one or more of the basic psychological processes involved in understanding or in using language, spoken or written, which disorder may manifest itself in an imperfect ability to listen, think, speak, read, write, spell, or do mathematical calculations. The term includes such conditions as perceptual handicaps, brain injury, minimal brain dysfunction, dyslexia, and developmental aphasia.

Visual Processing Disorder (VPD): The inability for the brain to correctly interpret the visual information that was taken in by the visual system. Visual processing is different from visual acuity, which is eyesight or what is commonly referred to as vision.

Visual processing: The brain's process of recognizing and interpreting information taken in through the sense of sight (Snowden, Thompson, & Troscianko, 2006).

Appendix F

Raw Data Results for the Three Groups

	PSI SCORE	COHERENT MOTION	WJIII – Math Calc	WJIII- Math Fluency
Math Only	97	10.64	95.00	96.00
	75	15.03	86.00	75.00
	73	72.00	66.00	71.00
	80	13.29	92.00	86.00
Math and Reading	100	13.78	91.00	90.00
	88	11.38	100.00	94.00
	88	14.62	99.00	92.00
	85	12.53	61.00	77.00
	80	17.40	86.00	86.00
	80	98.00	108.00	87.00
	94	13.17	94.00	76.00
	83	12.43	95.00	79.00
	78	78.25	69.00	66.00
	91	28.71	88.00	90.00
	75	15.90	68.00	68.00
	85	11.99	80.00	98.00
	83	25.74	101.00	92.00
Typical Child	121	35.65	111.00	96.00
	73	11.78	91.00	74.00
	109	25.59	115.00	96.00
	106	14.39	96.00	110.00
	103	16.29	98.00	82.00
	97	60.91	115.00	132.00
	100	13.53	113.00	110.00
	112	17.64	114.00	102.00
	115	4.82	131.00	126.00
	100	19.66	93.00	98.00
	100	10.25	121.00	118.00
	109	7.30	125.00	123.00
	118	13.88	125.00	109.00
	115	7.75	106.00	114.00
	128	6.36	118	126.00
	118	9.76	90	85.00