REACTIVITY TO STRESS AND THE COGNITIVE COMPONENTS OF MATH

DISABILITY IN GRADE 1 CHILDREN

by

MAUREEN MACKINNON-MCQUARRIE

B.A., University of British Columbia, 1978
M.A., University of British Columbia, 1988

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ABSTRACT

This study investigated the relationship between working memory, processing speed, math performance and reactivity to stress in 83 grade 1 children, 39 with math disability (MD) in comparison to 44 typically achieving (TA) children. The purpose of this study was to investigate the cognitive components of MD and to determine whether stress was interfering with the processes believed to underlie MD. This study is the first to use a physiological index of stress (cortisol levels in saliva) to measure reactivity to stress and learning in children while completing tasks believed to underlie MD. The overall hypothesis was that children with high reactivity would perform more poorly on the working memory tasks believed to underlie MD and that children with MD and high reactivity would exhibit the poorest performance on the tasks that were impaired in children with MD. Nine tasks were administered to assess the core components of MD: working memory for numbers, working memory for words, digits backwards, letter number sequence, digit span forwards, processing speed for numbers and words, block rotation and math tasks. Saliva samples were collected for analysis of cortisol at Time 1 (T1) as a pre-test baseline and Time 2 (T2) 30-minutes post-test as an index of stress. In addition, on a separate day, samples were collected Time 3 (T3) in the morning and Time 4 (T4) in the afternoon, to establish normal circadian rhythm. Participants were grouped by reactivity levels (high, moderate, and low) for effect size calculation. Children with MD were impaired on the Letter Number Sequence, and Quantitative Concepts tasks. Higher levels of reactivity significantly predicted poorer performance on the Working Memory for Numbers, Working Memory for Words, and Quantitative Concepts tasks. There were no differences between children with MD or TA in cortisol values at any of
the times, in reactivity or circadian rhythm. The findings suggest that children with high reactivity may benefit from methods of emotional regulation to reduce reactivity, which may improve learning. Practical implications for educators include attention to the stress response in children, the identification of children with high reactivity and the provision of contextual support.
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To Sandy, thank you for cooking, and to my son Nathan I am finished now (honestly) and will start to cook again.

To my parents and grandmother, who told me to get as much education as possible. I am wondering if this is enough?
DEDICATION

This dissertation is dedicated to all the teachers who have devoted their lives to teaching children with learning disabilities.
CHAPTER I: INTRODUCTION

Statement of the Problem

Math disability (MD) affects between 5% and 8% of all children in school (Badian, 1983; Gross-Tsur, Manor, & Shavel, 1996; Ostad, 1997; Shavel, Auerbach, Manor, & Gross-Tsur, 2000). The development of mathematical competency is important for participation in a rapidly advancing technological global economy. A significant body of literature indicates that children with MD exhibit a deficit in working memory. There are three components to working memory (Baddeley, 1986; Baddeley & Hitch, 1974). The first component is the central executive (the attention system involved in the simultaneous processing and storage of information, e.g., recalling numbers in reverse). The other two components are two passive storage systems: the phonological loop (the short term storage system for speech-based information, e.g., remembering numbers) and the visuospatial sketchpad (the short-term storage system for visual spatial information). Working memory deficits are believed to interfere with the ability to acquire mathematical skills in a number of ways, including the retrieval and consolidation of basic math facts, the execution of addition, subtraction, multiplication, and division calculations, math problem solving tasks, and counting-based procedures (Bull & Johnson, 1997; Geary, 2004; Hitch & McAuley, 1991; Passolunghi & Siegel, 2001, 2004; Siegel & Ryan, 1989; Swanson, & Sachse-Lee, 2001).

Processing speed (the ability to name numbers or pictures rapidly) has also been investigated as a possible core impairment in children with MD (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Hecht, Torgesen, Wagner, & Rashotte, 2001; Passolunghi & Siegel, 2004).
Limitations of Previous Research in MD

This study addresses two major limitations in previous research on MD. First, much of the research on MD has conflated MD and reading disability (RD) by comparing the performance of children with MD only and/or children with MD and (RD) with the performance of typically achieving children (TA) (Geary, Brown & Samaranayake, 1991; Hitch & McAuley, 1991). Conflating the two disabilities (MD and RD) limits the findings in terms of understanding the core cognitive components of MD. It is important to investigate whether children with MD only have a pattern of core cognitive deficits that is distinct from children who have both MD and RD. Second, other studies have used high cut-off scores e.g., 46th percentile on standardized math tests to identify the MD participants, which includes children functioning within the average range in mathematics (Geary, 1990; Geary, Brown, & Samaranayake, 1991). Also many of the previous studies have focused on older children and my study focused on grade 1 children with MD only, and used more stringent criteria (below the 25th percentile on standardized math tests and above the 30th percentile on standardized reading tasks) to select participants for that group.

A methodological concern in conducting research with young children is the issue of including false positives in the MD sample. False positives occur in samples of younger children because of the difficulty discriminating between grade 1 children with MD and grade 1 children with low achievement in math that is not due to a math disability. Grade 1 children with low achievement on standardized math tests have not been consistently found to have low achievement in math in grade 2 (Geary et al., 1999). This finding suggests that some grade 1 children with low math achievement do not have MD, and after some time in school their difficulties in math subside. Also, children with low math achievement in grade 1, who exhibit
average range math achievement in grade 2, do not show evidence of cognitive impairments in
grade 2 compared to those with low math achievement across both grades. Therefore, there is
risk that the sample of MD students in this study may include some false positives or students
without MD who have low scores on standardized math tests, but who do not necessarily have
MD. The presence of false positives in the MD sample can affect results by inflating scores on
tasks that children with MD are impaired on, and may lead to the conclusion that there are no
differences between groups, when true differences may exist. Research with older children does
not exhibit the same problem of false positives in their MD samples; older children followed
longitudinally continue to show evidence of MD one year later (Passolunghi & Siegel, 2004).

Stress, Anxiety and Math

Richardson and Suinn (1972) described math anxiety as the arousal or apprehension
associated with the manipulation of numbers in academic, private, and social environments.
Ashcraft and Kirk (2001) suggested that the experience of anxiety causes a disruption in working
memory and Ashcraft and Krause (2007) argued that when math anxiety is aroused, individuals
suffer from compromised working memory, which affects their ability to perform the math task.

There is evidence that anxiety affects performance on math tasks (Ashcraft & Kirk, 2001;
consistently perform more poorly on mathematics achievement tests than students with low math
anxiety, and when provided with anxiety reducing techniques, their performance in math
improves (Hembree, 1990).

This argument is consistent with research that has shown that human experiences that
involve social evaluation, such as public speaking (Kirchbaum, 1996), can activate the stress
response to a level that interferes with retrieval and encoding of information associated with the
declarative memory system: the memory system responsible for storing facts, such as math facts or events. The relationship between stress and memory and learning is curvilinear (de Kloet, Oitzl, & Joels, 1999). Low and high levels of stress disrupt cognitive processing (Elzinga & Roelofs, 2005; Kirschbaum, Wolf, May, Wippich, & Hellhammer, 1996; Kuhlman, Kirschbaum & Wolf, 2005; Lupien, Gillan, & Hauger, 1999) and moderate increases followed by a decrease enhance it (Blair, Granger, & Razza, 2005).

Cortisol is the hormone released in response to stress and it is now known that high levels of this hormone affect neuronal activity in the brain (hippocampus and prefrontal cortex) that are critical for novel declarative learning and memory. If stress interferes with the cognitive processes involved in learning declarative verbal information, then it could also be implicated in the working memory problems of children with MD. Children with MD may be particularly at risk for experiencing anxiety or stress due to repeated failures and poor self concept in math. This study examines this possibility. We tested the hypothesis that children with MD would have higher reactivity (measured by the change in cortisol levels during testing) compared to their TA peers and high reactivity would affect performance on the working memory, and processing speed tasks that are believed to underlie MD.

Limitations of Previous Research in Math Anxiety

Most research about math anxiety and math achievement has relied on self-report instruments to measure math anxiety (e.g., the Math Anxiety Rating Scale (MARS), Richardson & Suinn, 1972). Self-reports of anxiety can be helpful indicators of stress; however, much has been written about the unreliability of self-report methodologies (see Winne, Muis, & Jamieson-Noel, 2002; Winne & Perry, 2000 for reviews), and self-report measures are a particular concern for young children. Specifically, children have difficulty generalizing across time and settings,
which is required for most self-report tools (Turner, 1995). Also, they confuse intentions and actions, display positive response bias, and struggle with the language and response formats of many self-report measures (Cain & Dweck, 1995; Paris & Newman, 1990). Importantly, this study addresses these limitations by being the first to use a physiological index of stress (cortisol levels in saliva) to investigate whether the stress response interferes with cognitive processes involved in math performance, and whether the stress response is a particular problem for children with MD.

Limitations of Previous Research in Stress

Most of the research on stress and learning has examined the effects of stress on the retrieval and learning of verbal information in adult populations within the context of the laboratory. de Kloet et al. (1999) claim that to understand the effect of stress on human cognitive processes, research needs to investigate the stress response in naturalistic contexts and on a wider variety of tasks. My study is the first to address reactivity to stress and learning in children completing tasks involving working memory, processing speed, math computation and math problem solving skills. Moreover, my study involves children with and without MD to see if differences in stress reactivity exist between these two groups and how such differences affect math performance.

Literature Review

My review of literature is organized in four main sections and presents studies that provided the theoretical background for my research questions. First, I review studies that have investigated core cognitive components believed to be implicated in MD. Second, I review research that links anxiety and math performance in TA samples, including a few recent studies that have examined the relationship between self-reported math anxiety and performance on
working memory tasks. Third, I review findings from research that has linked physiological indicators of stress to cognitive processing; specifically, studies that have investigated the relationship between stress and the retrieval of verbal information, such as lists of words and working memory. Much of this research has been done with adults; however, my review includes the few studies that have involved children. Finally, I review research that has investigated self-concept in children with learning disabilities. This research is included as evidence that children with learning disabilities may be more prone to experiencing stress within the context of performing in their area of disability (e.g., math) due to repeated failure and low academic self-concept in that domain.

Core Deficits Associated with MD

Geary (1993) reviewed two bodies of research that investigated the core deficits of MD: a) studies that investigated the counting and arithmetic skills of children with MD in comparison to TA children, and b) research that investigated children with acquired dyscalculia (numerical deficits associated with brain injury). Based on this review, he concluded that children with MD differ from their TA peers in two ways: (a) they use error prone developmentally immature computational procedures to solve arithmetic problems (i.e., inefficient strategies); and (b) they have difficulties representing and retrieving numerical information such as arithmetic facts from long-term memory. He concluded that a weakness in the central executive or in the ability to allocate attention while computing arithmetic calculations and difficulties in the representation and retrieval of arithmetic facts from long-term memory were core components of MD.

Strategies

Immature strategy use is one of the identifying features of children with MD and it has been viewed as an adaptive strategy to compensate for poor working memory (Geary, 2004;
Geary & Hoard, 2002; Jordan & Montani, 1997). Compared to their TA peers, children with MD use a variety of immature computational strategies similar to younger children. They do not advance through the progression of strategy use at the same rate as their TA peers who gradually show a shift in strategy use from grade one to grade two by replacing finger counting with verbal counting and retrieval of number representations (Geary et al., 1999; Geary et al., 2000).

Typical Development and Use of Strategies

The progression and development of counting and computational strategies used by TA children to solve basic arithmetic computations has been well researched in the literature (Geary, 2004; Geary et al., 2007; Geary & Siegler, 1994; Gelman & Gallistel, 1978; Jordan & Montani, 1997; Siegler, 1988; Siegler & Shrager, 1984). At about age 2 to 3, preschool children in all cultures begin to use number words or word tags to count quantities (Gelman & Gallistel, 1978). By age 3 or 4, most children have learned the number words from one to ten. Children acquire proficiency counting when they have learned five implicit principles or rules of counting which are believed to be acquired inherently (Gallistel & Gelman, 1992; Gelman & Gallistel, 1978) and through observation. The principles are one to one correspondence (one word for each item counted), stable order (order of counting is the same in all sets), cardinality (the last name tag is the quantity in the set), abstraction (any item can be counted), and order irrelevance (items can be counted in any order). Children learn to count through observation and practise. They gradually and incidentally learn the essential rules of counting (Gelman & Gallistel, 1978) and the unessential features of counting (Briars & Siegler, 1984). As children learn to count, the unessential features of counting are often mistaken for essential rules, they include: standard direction, adjacency, pointing, and start-at-an-end (counting proceeds from left to right). By kindergarten age, most children can distinguish essential and unessential features of counting and
have the knowledge they need to count accurately and solve simple addition problems. However at age five most children still believe that adjacency and start-at-an-end are essential features of counting.

Once counting has been established, most kindergarten children begin to solve basic addition computation using the “counting all” or “sum” strategy, a technique where the child counts out both numbers either on their fingers or verbally, then counts the numbers from one to find the solution. The next strategy in the progression of strategy use is the “counting on” or “min” strategy or “max” strategy. In the “min” technique, the child states the larger number first and counts on to the solution (e.g., to solve 4 + 2, the student would count 4, 5, 6). In the “max” technique the child states the smaller number first then counts on to the solution. Decomposition is the next strategy in the progression of arithmetic development and it is used to break larger problems into smaller and easier computations (e.g., 5 + 8 could be broken down into 5 + 5 and then add 3). Finally, the last strategy is automatic retrieval where math facts are represented in long-term memory and can be retrieved without the use of counting procedures (see Geary et al., 2007 for a review; Siegler, 1988). The general progression of strategy use in TA children is: counting all fingers using the “sum” procedure, then finger counting and or verbal counting using the “min” or “max” procedure, decomposition, and finally automatic retrieval.

After some time, the use of finger and verbal counting strategies using the sum and min procedure lead to memory representations of math facts develop in long-term semantic memory. Once math facts are represented in long term memory, they can be accessed through automatic retrieval for computations without the involvement of working memory. The automatic retrieval of number representations results in faster solution times compared to immature strategies such as finger counting and the sum procedure, which tend to be more prone to error. TA children
retrieve basic math facts effortlessly and add and subtract automatically without the use of finger counting. When automatic memory retrieval is not an option to solve a more complex exercise, such as carrying, children return to immature counting strategies or procedure-based processing methods. These methods are slower, are more susceptible to error, and require working memory whereas automatic retrieval from long-term memory does not (Geary, 1993, 2004; Geary, Hoard, Byrd-Craven, & De Soto, 2004; Jordan & Montani, 1997).

Strategy Development in Children with MD

Geary et al. (2000) found that grade 1 and 2 children with MD relied on finger counting more and used the sum procedure more and the min procedure less than TA children. These findings are consistent with other studies that have investigated strategy use in children with MD (Barrouillet, Fayol, & Lathuliere, 1997; Geary, 1993; Jordan & Montani, 1997; Ostad, 1997, 1998).

Geary et al. (2004) assessed the abilities of children in grades 1, 3, and 5 by comparing children with MD to their TA peers on measures of working memory and by observing the frequency of strategy use while children solved simple calculations, such as $4 + 3$, and complex addition tasks, such as $16 + 8$. On the simple addition tasks, grade 1 children with MD used finger counting more than their TA peers, committed more errors when using finger counting and retrieval, and relied on the sum procedure more than the min procedure than their TA peers. There were fewer group differences in strategy use, error percentage, and use of min procedure in grades 3 and 5, although grade 5 children with MD used finger counting more than their TA peers. For complex addition tasks, the grade 1 children with MD used retrieval more than their TA peers, who relied on the min procedure. However, the MD children had a higher rate of errors suggesting that guessing was the strategy rather than retrieval. Grade 3 children with MD
committed more decomposition errors and exhibited a tendency towards more finger and verbal counting errors than their TA peers.

The study of strategy use in children with MD revealed three characteristics that differentiated them from their TA peers: (a) poor retrieval of basic arithmetic facts (Geary, 2004), (b) the presence of irrelevant associations during the retrieval process (Barrouillet et al., 1997; Geary et al., 2000; Passolunghi & Siegel, 2001, 2004), and (c) the use of developmentally immature strategies, such as finger and verbal counting and the sum procedure (Bull & Johnson, 1997; Geary, et al., 2004; Jordan & Montani, 1997).

As children advance in mathematics, working memory continues to be required. More complex mathematics questions such as two column addition are more prone to errors and take longer to solve (Ashcraft & Krause, 2007). For example, $6 + 8$ or $8 \times 9$ takes more time to solve and produces more errors than $2 + 4$ or $3 \times 2$. Part of this problem has been attributed to the "frequency effect" or the inverse relationship between problem size and frequency of this type of question in textbooks. Larger problems occur less frequently in textbooks and less exposure and practise lead to lower levels of memory (Hamann & Ashcraft, 1986). Without automatic retrieval, a return to immature strategies and working memory is required to solve the problem.

The success of developing accurate representations in long-term memory has been attributed to working memory capacity (Geary et al., 1991). Speed of counting, or the amount of information that can be rehearsed is related to the amount of resources available in working memory (Baddeley, 1986; Kail, 1991). That is, as children retrieve name tags faster or learn to count faster, they use more efficient strategies, creating more resources in working memory to begin to form accurate numerical associations for basic math facts in long-term memory. The relationship between working memory capacity for both numbers and words, and processing
speed (the ability to rapidly name numbers or words) is not conclusive, but both processes have been investigated as core components of MD (Geary et al., 2007; Passolunghi & Siegel 2001; 2004).

**Math Disability and Working Memory**

Children with MD exhibit difficulties with dual processing tasks, or working memory tasks that require them to store and process information simultaneously, such as recalling a list of numbers in reverse or recalling words after hearing a series of sentences. However, the research findings are inconsistent. Some researchers have found that children with MD exhibit a domain specific deficit in working memory, or a deficit in working memory for numerical information but not for verbal information (Geary et al., 2004; Geary et al., 1999; Hitch & McAuley, 1991; Landerl & Butterworth, 2004; McLean & Hitch, 1999; Siegel & Ryan, 1989). Others have found a general deficit in working memory or an impairment on working memory tasks that involved both numbers and words (Ashcraft & Kirk, 2001; Passolunghi & Siegel, 2001, 2004).

Researchers have posited different explanations for the weaknesses in working memory in children with MD. In their meta analysis of 28 studies that investigated MD, Swanson and Jerman (2006) concluded that controlled attention or the ability to focus in on verbal information was a defining feature of MD. Other studies suggest that the deficit in working memory for both numbers and words is linked to an impairment in the central executive and the inhibitory process during retrieval. This impairment in the inhibitory process is posited to result in intrusion errors and the selection of erroneous sequential associations of numbers that are presented in the questions, or in words that are imbedded in the sentences on the listening span tasks (Barrouillet et al., 1997; Passolunghi & Siegel, 2001, 2004). Other studies have found that slow processing speed for numbers or words is impaired in children with MD (Geary et al., 2007). Evidence of a
processing speed impairment has been implicated by some researchers (Bull & Johnson, 1997; Kail, 1991) as an explanation for the deficits in working memory for both numbers and words due to the slow retrieval of memory representations, but this is still debated in the literature.

Studies that have not found an impairment in processing speed in children with MD and working memory deficits suggest that an impairment in the inhibitory processes of the central executive may be at the core of difficulties in working memory (Passolunghi & Siegel, 2004).

Working Memory for Numerical Information

Siegel and Ryan (1989) were the first to demonstrate that performance on a counting span task differentiated TA children and children with RD and MD combined and children with MD only. The children with a combination of RD and MD demonstrated a general deficit in working memory by scoring significantly lower on complex working memory tasks such as the listening span, a working memory task involving words, and the counting span task, a working memory task involving numbers (Case, Kurland, & Goldberg, 1982). Children with MD only, exhibited difficulty with the working memory counting span task, but not the working memory for words task. Siegel and Ryan (1989) speculated that their findings were indicative of a specific working memory deficit in the processing of numerical information for children with MD only and those children with RD and MD combined had a more general deficit in working memory that affected both numbers and words. From this point in the literature review I will focus on research results that are for children with MD only.

Hitch and McAuley (1991) compared 15 children (8 to 9 years old) with MD to 15 TA controls, on complex working memory tasks. They wanted to investigate the differences in the development of working memory in TA children and children with MD using the counting span task (numerical) and sentence span task (verbal). Their findings were consistent with Siegel and
Ryan (1989); children with MD were impaired on the counting span task only indicating a deficit in processing numbers, but not for verbal information. Numerous additional studies have found that working memory for numerical information is impaired in children with MD (Geary, Brown, Samaranayake, 1991; Geary et al., 2004; Geary et al., 1999; Hitch & McAuley, 1991; McLean & Hitch 1999; Ryan & Siegel, 1989). Geary et al. (2004) found that for children with MD, working memory for numbers (counting span task) was about one year behind TA children across grades 1, 3 and 5.

Working Memory for Verbal Information

There is research that shows that students with MD do have difficulty with some kinds of verbal information (Keeler & Swanson, 2001; Passolunghi & Siegel, 2001; 2004; Swanson & Beebe-Frankenburger, 2004). Passolunghi and Siegel (2004) found that grade 5 children with MD had significantly poorer performance on all complex working memory tasks whether they involved words or numbers, supporting a generalized working memory deficit in children with MD that they attributed to a weakness in the inhibitory processes of the central executive or an inability to ignore irrelevant information such as intrusion errors. Other studies have also found that working memory for verbal information is impaired in children with MD. Swanson and Jerman (2006) conducted a selective meta-analysis of the literature on cognitive functioning of children with MD and their TA peers and found results that are consistent with previous synthesis of the literature on MD and working memory (Geary 1993, 2004). When the effects of all other variables and domains were controlled, the differences between the children with MD and TA were primarily related to verbal working memory. Swanson and Jerman (2006) found that controlled attention to verbal information and a weakness in verbal working memory are the defining features of MD. They speculate that semantic memory deficits may underlie MD, and
they found little support for the theory that distinct processes underlie RD and MD and suggest that the common deficit between the two groups could lie in the area of executive function and working memory.

The question of whether both verbal or numerical working memory are impaired in children with MD has not been entirely resolved. The research appears to be consistent in several aspects; most researchers have found an impairment in at least one domain of working memory or in a combination of working memory areas, that is verbal, numerical and/or visual spatial information. The consistent finding of impairment in working memory has led a number of researchers to suggest that the distinguishing feature of MD may lie in the inhibitory processes (Passolunghi & Siegel 2001; 2004) or in controlled attention of the central executive (Swanson & Jerman, 2006). This study is designed to clarify whether working memory for verbal information is impaired in grade 1 children with MD only.

Short-term storage. Numerous studies have focused on which of the specific components of working memory, namely the central executive, phonological loop, and visuospatial sketchpad, account for the variance in the development of specific math cognitive skills (Geary et al., 2007; Passolunghi & Siegel, 2004).

Researchers have been particularly interested in whether short-term capacity of the phonological loop for small amounts of speech based information is related to deficits in working memory for numerical or verbal information or both. The findings from these studies are mixed. Some studies found evidence of a deficit in short-term memory storage for numbers in children with MD (Hitch & McAuley, 1991; Passolunghi & Siegel, 2001) while other studies have not (Bull & Johnson, 1997; Geary et al., 2000; Geary et al., 1999; McLean & Hitch, 1999, Passolunghi & Siegel, 2004; Swanson & Jerman, 2006).
Passolunghi and Siegel (2001) did not find that short term storage capacity for verbal information distinguished grade four children with MD from their TA peers. However, children with MD exhibited lower performance than the TA children in the recall of numerical information (Digit Span Forward). They interpreted this finding as a possible difficulty with slower access to number representations in long term memory which contributed to slow counting speed. These findings are consistent with other studies that have found the short term storage capacity to be impaired in children with MD (Hitch & McAuley, 1991). My study aims to verify whether short term storage for numbers is an area of deficit in grade one children with MD.

Processing speed. Processing speed or speed of naming numbers and words has also been investigated as a deficit underlying MD, primarily because of its possible link to influencing working memory capacity (Geary et al., 2007; Hitch & McAuley, 1991; Passolunghi & Siegel, 2004; Swanson & Beebe-Frankenberger, 2004).

Hitch and McAuley (1991) found that 8 to 9 year old children with MD were significantly slower at counting dots on the working memory for numbers task (counting span task) than their TA peers. They explained the poor performance on the working memory task to be due to slow articulation rate (processing speed) caused by difficulty accessing representations in long-term memory. They argued that lack of experience counting could be the cause of slow counting contributing to the longer time involved in retrieving the information from long term memory. Bull and Johnson (1997) found slow articulation rates for words and numbers in seven year old children with arithmetic difficulties, but when reading was controlled for the differences in speed of articulation for words were no longer significant. Geary et al. (2007) found that 6 year old children with severe MD only (below 16 percentile on measures of math achievement
for two consecutive years) were impaired on processing speed tasks for numbers and letters compared to TA children.

Passolunghi and Siegel (2004) investigated this question in grade 5 children with MD in comparison to TA children. They did not find evidence of slow articulation rates for numbers or words in grade 5 children with MD compared to TA peers. These findings are consistent with Geary et al. (2000), who did not find differences between grade 1 and 2 children with MD and TA on the processing speed tasks for numbers or words.

In addition, the findings for processing speed impairment in children with MD are inconsistent. Some studies have found that processing speed for numbers and numbers and letters are impaired (Bull & Johnson 1997; Geary et al., 2007; Hitch & McAuley, 1991; Swanson & Jerman, 2006) while other studies have not found a processing speed impairment for numbers or words in children with MD (Geary, 1990; Geary & Brown, 1991; Geary et al., 2000; Passolunghi & Siegel, 2004). Some studies that have found a processing speed deficit have discovered that when reading ability and nonverbal intelligence are partialed out, processing speed did not contribute unique variance to the model (Swanson & Beebe-Frankenberger, 2004). Another study found that processing speed was impaired only in the children with the most severe math disability (Geary et. al., 2007). My study aims to further clarify whether processing speed is impaired in grade one children with MD.

Visual spatial. Geary’s taxonomy of MD (Geary, 1993, 2004) includes a visual spatial subtype of MD, although there have been very few studies to systematically research spatial abilities in children with MD. One of the problems with the research conducted into the visual spatial abilities of children with MD are the varying types of tasks used to measure the construct of visual spatial ability. For example, from four studies that included visual spatial tasks, each
one included different visual spatial tasks, including mazes, block recall, block design, object assembly, visual matrix span, mapping and directions, and corsi span. The mazes subtest (WISC-III) is a task designed to measure visual spatial ability that requires motor skills. The subject is presented with a maze and a pencil and is required to trace a path by drawing a line from the start without crossing the line barriers to the finish. Block Design (WISC-III) is a timed task used to assess visual spatial organization and it also requires visual motor skills. In this subtest the presenter builds a geometric design that is made from three dimensional cubes and the subject is required to reproduce the design using the cubes. As the test progresses, the subject is required to reproduce a design from a picture of cubes that have been arranged into a geometric design. Object Assembly (WISC-III) is a timed task designed to measure visual organization, part to whole synthesis and it also requires motor coordination. The subject is presented with puzzle pieces of common objects such as a car or a soccer ball that they are required to assemble within a specific time limit. Visual matrix span is a span task that does not require motor skills. It is designed to measure visual working memory span for random visuospatial patterns of increasing difficulty. The subject is presented with a matrix on a computer screen then is presented a blank screen followed by a matrix that is similar to the original but with a change in the pattern. Subjects are required to identify the portion of the matrix that changed by pointing at the spot on the screen. Mapping and directions is a task designed to measure the ability to recall visual spatial directions and it also requires visual motor skills. The subject is presented with a street map with lines connected to a number of dots that illustrate the direction a bike would travel to get through a city. The dots represent stoplights and the lines the direction the bicycle should travel. The subject is then presented with a blank map and the subject is required to complete the map by filling in dots. The Corsi block span (Milner,
1971) is a task designed to measure spatial temporal ability or spatial span. The subject is presented with a board with blocks that have been glued to random positions. The presenter taps a sequence of blocks and the subject is required to reproduce the tapping sequence. The blocks are numbered 1 through 9 to help the subject recall the sequences.

Geary (1993, 2004) describes a visual spatial subtype of math disability wherein a student displays difficulties in spatially representing numerical information (e.g., manoeuvring spatial information), although he acknowledges that the research has been inconclusive in this area due to the methodological issues discussed earlier. Some of the research that has been conducted in this area of visual spatial abilities and MD is discussed below.

McLean and Hitch (1999) found impairment in working memory for spatial information (visual matrix span) in grade 3 and 4 children with MD compared to their ability matched peers and age matched peers. Swanson and Jerman (2006) report a significant effect size from 13 studies for visual spatial working memory between the children with MD and TA. They argue that this is evidence that working memory deficits operate outside a domain specific system.

Rourke (1993) reviewed studies that compared children with MD to TA peers on visual spatial tasks and found children age 9 to 14 years with MD performed significantly more poorly than their TA peers on the WISC-R Block Design and Object Assembly subtests (Wechsler, 1974).

Keeler and Swanson (2001) included a visual spatial working memory task (mapping and directions) in their investigation. They found that 10 year old children with MD performed in a similar manner to younger children matched by ability.

Geary et al. (2000) administered the Mazes subtest (WISC-III) to children with MD and TA in grades 1 and 2 and found no significant group differences between the children. Geary et
al. (2007) found significant differences between 6 year old children with severe MD and TA children on the Block Recall and Mazes tasks.

More systematic investigation with agreement on the type of tasks that are used to assess the visual spatial abilities of children with MD is needed (Geary, 2004).

Intrusion errors and inhibitory control. Another area that has been investigated in MD is the role of inhibition of irrelevant associations during retrieval because of its possible connection to working memory (Barrouillet et al., 1997; Geary et al., 2000; Passolunghi & Siegel, 2001; 2004). These studies investigated the presence of irrelevant associations during working memory tasks or during the computation of basic arithmetic addition or multiplication tasks. Evidence of erroneous associations during working memory tasks or basic addition and multiplication tasks has been viewed as evidence of an impairment in the inhibitory mechanism in the central executive. This impairment is believed to be involved in and connected to the impaired working memory processes found in children with MD.

Passolunghi and Siegel (2001) examined the relationship between inhibitory control and arithmetic word problem solving in grade 4 children who were poor in arithmetic problem solving (below the 30th percentile on standardized mathematics achievement tests) in comparison to their TA peers. They hypothesized that children who were poor problem solvers had working memory deficits that were due to an inability to control and ignore irrelevant information, and this would be shown by more intrusion errors during retrieval than their peers. They examined responses from the listening task where children provided the final word in a series of sentences. Intrusion errors were counted when words were recalled that were embedded in the sentence rather than the final word. On the counting span tasks, an intrusion was the recall of the number from the card presented before the current card. Children with MD exhibited significantly more
intrusion errors during recall on both tasks, which is consistent with the prediction that they would have difficulty with inhibition of irrelevant associations during retrieval.

In another study, Passolunghi and Siegel (2004) were interested in whether the presence of intrusion errors or a deficit in the ability to inhibit irrelevant information interfered with working memory. This study aimed to examine the cognitive mechanisms that lead to impaired working memory in grade 5 children with MD, in particular the role of inhibition of irrelevant information by counting the number of intrusion errors during working memory tasks. Again, they found that grade 5 children with MD had significantly more intrusion errors on the listening span task and the listening span completion tasks, a finding consistent with Barrouillet et al. (1997) and Passolunghi and Siegel (2001), indicating that children with MD experience an inability to inhibit irrelevant information during working memory tasks that involve verbal information.

Barrouillet et al. (1997) conducted an experiment to investigate whether incorrect responses were due to an impairment in the inhibitory mechanism during simple multiplication tasks. Children with MD and TA in grade 7 and 8 completed multiplication tasks and were presented with the correct response and three distractor responses. The level of interference was different for each response ranging from strong interference, where the response was a number from multiplication tables a or b, weak interference, the response was a number from tables belonging to other tables than a or b, or null interference, the numbers did not belong to the multiplication table. The strong interference condition resulted in more errors than the other two conditions. The authors concluded that inefficient inhibition increases incorrect responses.

Geary et al. (2000) conducted a longitudinal study that investigated the cognitive competencies of grade 1 and grade 2 children with RD, MD/RD, and MD in comparison to TA
children. They found that the MD group differed from TA children by showing more retrieval errors than their TA peers. They found a high proportion of the retrieval errors were associates of one of the addends (e.g., $2 + 5 = 6$). This finding supports the inefficient inhibition or irrelevant associations explanation for the retrieval deficits of children with MD consistent with other studies (Barrouillet et al., 1997; Geary, 1993; Passolunghi & Siegel, 2001; 2004) and the hypothesis that retrieval difficulties are due to the poor inhibition of irrelevant associations.

In summary, the research concerning working memory to date suggests the two key areas of deficit in children with MD are: (a) working memory for numerical information, and possibly for verbal information, and (b) in the retrieval process and difficulty accessing accurate long-term memory representations due to interference from irrelevant associations. A few studies have included a measure of visual spatial working memory or visual spatial manipulation and have found evidence of a deficit in this area in children with MD, but the tasks have been inconsistent across studies and it is difficult to make any generalizations. It is still not clear whether short term memory storage of numerical information and processing speed are core components of MD as findings have been inconsistent on these tasks.

For the student with MD, working memory performance for numerical information is consistently behind their TA peers, and working memory performance for verbal information may also be implicated. The ability to represent and retrieve basic arithmetic facts remains behind their TA peers across elementary school years (Geary, 2004), with consistent evidence of interference by irrelevant associations during the retrieval process (Passolunghi & Siegel 2001; 2004). Children with MD continue to use finger and verbal counting and the sum and min procedures after their TA peers to compensate for their lack of mastery of math facts to long-term memory. Working memory capacity has been shown to be at least one grade-level behind
their TA peers. Both children with MD and TA children show continuous growth in working memory up until about age eighteen; however, children with MD remain consistently behind their TA peers, showing persistent working memory and retrieval problems.

Math Anxiety, Working Memory, and Performance in Math

Although educational researchers identified working memory as a common deficit in children with MD, a number of other studies have demonstrated that math anxiety affects both performance on math tasks and working memory for computational tasks. Ashcraft and Kirk (2001) tested whether math anxiety could be related to difficulties with the execution of working memory tasks in undergraduate college students. They conducted three experiments to assess math anxiety and performance on working memory tasks. For all three experiments, participants were divided into those with high, medium or low math anxiety based on self-report scales, such as the short Mathematics Anxiety Rating Scale (sMARS; Alexander & Martray, 1989). In the first experiment, participants completed two span tasks (listening span for words and addition span for numbers). On the listening span task, participants heard a series of simple sentences and were asked a question about the sentence before hearing the next sentence. They were then required to repeat back the last word in each sentence. On the numerical task, participants heard a sequence of digits and were then required to simultaneously process a simple arithmetic task then provide the initial sequence of digits. The individuals with high math anxiety obtained significantly lower scores on the working memory tasks than the low anxiety group. These results suggested that individuals with higher levels of math anxiety have a reduced working memory capacity on either computation based or language based span tasks. They found that the anxiety group (high, medium, or low) was more predictive of the span tasks for computation than
for the span score for language. They argued that this finding is evidence that those aspects of math performance that require working memory for numbers are most affected by math anxiety.

In the second experiment, the researchers further explored the relationship between math anxiety and addition computational tasks that ranged in difficulty from single digit (e.g., 4 + 3) to double digit questions with carrying (e.g., 43 + 18). They added a secondary memory load to the task by requiring the participants to hold either two or six random letters in working memory for recall later. They found that on the more difficult items, all anxiety groups exhibited more errors, but the high anxiety group exhibited significantly more errors suggesting that they had the least working memory capacity to devote to the dual processing task. They suggested that math anxiety affects working memory by reducing working memory span when assessed with computation-based span tasks.

Experiment 3 was designed to explore whether compromised working memory was extended to working memory tasks that do not require learned math procedures. They wanted to determine whether math anxiety was triggered specifically by math tasks or whether tasks that used number related processes such as working memory tasks for numerical or counting type tasks had the same disruptive effect on working memory as computation tasks. Participants were given the same word span and computational working memory tasks in experiment 1 and a letter and a number transformation task. The letter transformation tasks required the subjects to transform letters mentally by moving forward either two or four steps through the alphabet and holding the response in memory while performing the next item. Similarly a number transformation task was added to this experiment where subjects were given a sequence of numbers, such as “15, 3, 25, 19,” and they had to add 7 to each number. After the transformation the participant would report “22, 10, 32, 26.”
The results of this experiment indicated that the overall effect of math anxiety was the same for the computation span and listening span tasks. However as math anxiety increased the computation span scores declined, but the listening span scores did not. The authors concluded that there was a decline in working-memory span for numerical information related to the level of math anxiety. For the transformation tasks, the high-math-anxiety participants spent more time on the transformation than the low and medium-anxiety groups. They found no differences on recall accuracy as a function of letter versus number transformation. They concluded that working memory tasks that require counting type processes trigger math anxiety and disrupt working memory whether they involve numbers or letters, but not words.

The majority of research into math anxiety and math performance has been conducted with self-report scales such as the Math Anxiety Rating Scale (MARS) in samples of students that are not specifically MD. Hembree (1990) conducted a meta-analysis of the early literature into math anxiety assessed by self-report scales and performance in mathematics to integrate the findings of research in this area. He calculated the effect size for thirteen studies involving college students who had completed math anxiety self-report scales and standardized math tests. The mean effect size was -.61, indicating that the high anxiety groups scored .61 of a standard deviation below those with self-reported low anxiety on standardized math tests. Hembree (1990) concluded from this meta-analysis that as self-reports of math anxiety rise, performance on standardized math achievement tests declines.

Ashcraft and Krause (2007) discuss their findings from an earlier study (Seyler, Kirk, & Ashcraft, 2003) where they collected scores from 80 college students on the Wide Range Achievement Test (WRAT), a standardized math achievement test and their relationship to scores on self-reports of math anxiety. They found a negative correlation (r = -.35) between math
anxiety and the composite WRAT score. They then analysed the WRAT performance in detail because of the increasing level of difficulty of items. They found that in the beginning of the test when retrieval strategies were used for whole number arithmetic, no differences emerged. On the more difficult lines of the test, where the students used carrying strategies that require working memory (e.g., multiplication of fractions), the high anxiety group made significantly more errors compared to the low math anxiety group.

They investigated how the self-reported experience of high math anxiety affects working memory by administering a variety of working memory tasks using numbers and words. They found no significant differences among the anxiety groups on verbal span tasks, but found that when a computational-based span task was administered, the high math anxiety group had a significant decline in working memory capacity. They contend that this is evidence that working memory is compromised only when math anxiety is aroused. If math anxiety affects performance in math and working memory for TA individuals, it may further exacerbate the difficulties of children with MD and contribute to their difficulties in math computation.

Researchers have observed an inverse relationship between self-reported math anxiety and math performance— as the self-reports of math anxiety increase in high school and college students, their math performance decreases. It has been suggested that it is the arousal of anxiety that creates a reduction in the availability of working memory capacity by slowing the access to information (Eysenck & Calvo, 1992). A reduced working memory capacity affects performance on math tasks that require working memory, such as the carrying procedure in addition and multiplication, regrouping subtraction, and the use of strategies and procedures that involve counting versus automatic retrieval (Ashcraft & Krause, 2007). Therefore, the arousal of anxiety may play a role in the working memory deficits of children with MD. Faust’s study (as cited in
Ashcraft, 2002) found physiological evidence of increased reactivity (e.g., changes in heart rate) in individuals with self-reported math anxiety during the execution of math tasks, but during verbal tasks reactivity was not demonstrated (Ashcraft, 1995). There has been no research conducted to investigate anxiety using a physiological index of reactivity, and performance in working memory and math in grade 1 children with MD. Research has shown that students with self-reported high math anxiety have lower scores on computational tasks or standardized math tests than students with low math anxiety (Ashcraft & Kirk, 2001; Ashcraft, Kirk, & Hopko, 1998; Hembree, 1990). My study will investigate the link between anxiety/stress and working memory and math performance in children with MD with the use of a physiological index of stress, rather than the self-report measures used in research to assess anxiety.

**Stress and Cognitive Processing**

To understand how stress can affect the cognitive processes involved in learning and memory, it is necessary to define stress. Both psychological and physical stressors can evoke the stress response, disrupt homeostasis, and produce changes in autonomic responses, such as heart rate and blood pressure and increased levels of cortisol. Psychological stress requires an individual to subjectively process or interpret stimuli as threatening. The stressor can be any perception, event, or experience that disrupts "homeostasis" or physiological balance (Johnson, Kamilaris, Chrousos, & Gold, 1992). Examples of psychological stressors that have been demonstrated to naturally and consistently activate the stress response are public speaking (Kirschbaum, 1996), threat to social self (Dickerson & Kemeny, 2004), shame (Miller, Chen, & Zhou, 2007), test taking, and performance on math tasks (Hembree, 1990). My study will measure the change in cortisol levels from basal levels, i.e., before testing when the stressor is not
present, to 30 minutes following the start of testing, i.e., introduction of the stressor, as an index of stress in children with MD.

Cortisol Production

There are two ways that cortisol levels vary at any given time: (a) the circadian rhythm which varies widely according to the daily 24 hour cycle, and (b) the individual’s response to a stressor. Regarding circadian rhythms, the highest levels of cortisol are in the morning followed by a decline throughout the day towards the lowest levels, which occur during sleep. For the average human, normal circadian levels of cortisol at 8 AM can range from 3-20 ug/dL (micrograms per decilitre) with the average ranging from 10-12 ug/dL. By late afternoon, cortisol levels have dropped by half from the morning levels and continue to decline to their lowest level after midnight (Aaron, Findling & Tyrrell, 2007).

Variation in the Response to Stress

Wide variations in individual biological reactivity to environmental stress have been shown in humans (Boyce & Ellis, 2005). This study examines whether children with MD have a stress response that is significantly different from their TA peers when presented with working memory or process speed tasks and whether children with high reactivity (i.e., high stress) show performance differences on these tasks.

Boyce and Ellis (2005) identify two phenotypes in reactivity to stress: the highly reactive and the moderately reactive. They describe the highly reactive subtype as more sensitive to contextual threats in the environment, but also as more sensitive to supportive cues in the environment. The highly reactive phenotype does well in conditions of support and lower perceived stress, but in conditions where there is low support, their heightened reactivity can eventually result in chronic and affective disorders, such as depression, or anxiety. The
moderately reactive response is a slower reaction to stress with less pronounced physiological arousal. The more subdued physiological response to stress is considered maladaptive in situations of real physical threat that require sensitivity to contextual cues of threat and high levels of biological response to prepare for rapid escape.

Boyce and Ellis (2005) refer to a third response to stress: a flattened or lowered cortisol response. The reduced response has been observed in groups of children exposed to habitual or chronic stress, such as living near the centre of a major earthquake (Goenjian et al., 1996), orphans living inside Romanian institutions (Carlson & Earls, 1997), and preterm infants (Haley Weinberg, Grunau, 2006) in the first three months of life.

Declarative Memory System

The declarative memory system, involving the medial temporal lobe, hippocampus, and prefrontal cortex, supports the formation of novel declarative memories (memory for information) and is linked to the stress system. The consolidation and retrieval of arithmetic facts and the learning of novel semantic information, such as math facts, are dependent upon the declarative memory system. Non-declarative, or procedural memory is memory for skills such as bike riding, habits, and associative memory. Research has established that stress initiates cortisol production in humans and elevations in cortisol impair the functioning of the declarative memory system (Kuhlmann, Piel, & Wolf, 2005; Lupien & McEwen, 1997; Wolf, 2009).

Although working memory is different from semantic or episodic memory, working memory involves conscious awareness and access to semantic information (Baddeley, 2000) and, therefore, is considered part of the declarative memory system (Budson & Price, 2005).
Psychologists have investigated the relations between the psychological perception of stress or anxiety, the physiological arousal of the stress system, and performance on declarative memory tasks including verbal and working memory in adults. The majority of these studies have taken place in the laboratory. Some of these studies have used non-standardized tasks such as learning a list of words for later recall, or recall of events in a film. Other studies have used standardized measures of working memory, such as digit span and paragraph recall tasks. Recent studies have used physiological markers of stress (e.g., cortisol) in the context of completing working memory and short-term memory tasks.

The results indicate that adults with significantly elevated cortisol levels due to stress or emotional arousal have impaired performance in working memory for numbers and or short-term memory (Elzinga & Roelofs, 2005; Lupien, et al., 1999; Oie, Everaerd, Elzinga, van Well, & Bermond, 2006), retrieval and consolidation of semantic memory (Buchanan & Lovallo, 2001; Kirschbaum et al., 1996; Kuhlmann et al., 2005; Lupien & Lepage, 2001), and spatial memory tasks (Lupien et al., 2005). These are declarative memory tasks that are associated with the hippocampus and prefrontal cortex, anatomical sites in the brain that are part of the limbic system and linked to the stress system. The hippocampus and prefrontal cortex are also required for novel declarative learning and memory to occur (Nadel & Moscovitch 1997; Scoville & Milner, 1957; Squire, Stark, & Clark, 2004; Squire & Zola, 1996) and both are part of the neural circuitry of the stress system and are affected by stress. Similar findings have been found for animals as for humans.

Early studies examined the effects of elevated cortisol levels by administering cortisol or by exposing participants to psychosocial stress (Kirschbaum, 1993; Kirchbaum et al., 1996) or
physical stress challenges. More recent studies have investigated reactivity to stress within specific natural contexts and examined its relationship with novel declarative memory learning. Generally the findings in adult studies have been consistent. Herbert et al. (2006) reviewed studies that investigated the effects of excessive levels of cortisol on the brain and concluded that the effect of cortisol on cognitive function is bi-directional or reciprocal. It appears cortisol can effect cognitive function (e.g., working memory) and cognitive processing (e.g., the negative ideation associated with anxiety has an effect on cortisol production). My study will examine the relationship between cortisol and cognitive processing in children with MD and TA children.

Cortisol Timing and Type of Information

The timing of the experiment within the circadian rhythm (AM or PM) and the timing of manipulation in relation to the task (pre or post) are shown to affect performance on different types of memory tasks. The effect of cortisol depends on the type of process being measured, retrieval or consolidation, the type of information to be remembered, semantic or episodic, and whether or not the information can be considered neutral or emotional.

Emotional information has been shown to be affected by stress more than neutral information. High levels of cortisol have been demonstrated to affect memory processes for emotional or arousing information, with retrieval impaired (Kuhlmann et al., 2005; Maheu, Collicutt, Kornik, Moszkowski, & Lupien, 2005). For individuals with math anxiety, math tasks or tasks involving the manipulation of numbers can be considered emotional information as it evokes the stress response (Richardson & Suinn, 1972). Children with MD may be more prone to math anxiety because of frequent failure and may perceive math questions or working memory tasks involving manipulating numbers as emotionally arousing information, which has been shown to be more sensitive to the effect of stress.
Stress and Sex

Sauro, Jorgnesen, and Pedlow (2003) conducted a meta-analysis for the effects of stress on memory performance and cortisol. They found that sex was an important factor in the magnitude of stress response. Males exhibited higher cortisol levels in response to stress than females. They also found that correlations between cortisol levels and memory deficits were larger for studies that used individual event stressors rather than those that examined long-term exposure to stress.

Stress, Memory, and Learning in Children

Although the preponderance of studies investigating the effects of stress on the declarative memory system have been conducted with adults, there are a small number of studies that examine the relationship between stress in children and learning. These are of particular relevance to my study.

Blair et al. (2005) examined the relationship between stress and learning by collecting cortisol samples and assessing cognitive function in 4 to 5 year old children from low income homes. Cortisol levels were collected before (T1), during (T2), and after testing (T3) on measures of the central executive, receptive vocabulary, letter knowledge, and false belief understanding. The first sample measured cortisol levels when children were in the classroom, the second measured levels at the start of testing, and the third measured the levels during testing. Lower levels at the first and third sample (during testing) and higher levels at the second sample (at the start of testing) were associated with higher scores on the letter knowledge task. Lower levels at T2 (during testing) were associated with greater self-regulation as reported by teachers. A moderate increase in cortisol between the first and second sample followed by a decline in the increase during testing was associated with better performance on measures of
executive function, self regulation, and letter knowledge. My study will investigate whether a high stress response interferes with the cognitive processes believed to underlie MD.

Jimerson, Durbrow, Adam, Gunnar, and Bozoky (2006) examined the relationship between academic achievement, attention problems, and cortisol levels in 86 children ages 5 to 12, living in a rural Caribbean village. This study hypothesized that, for some children, cortisol levels would be elevated because of the anticipation of negative experiences such as poor academic performance, test taking, or poor relations with peers and teachers. The second hypothesis was that the children with elevated cortisol levels would have poorer adjustment, show more attention problems, and poorer academic performance than those with lower cortisol levels. The results indicated that for children with inattention-internalizing problems, there was a significant association between high cortisol levels and poorer academic performance. In addition, the researchers examined the associations between high cortisol elevation and academic performance for children with and without inattention-internalizing problems. Poor academic performance and high cortisol levels were found only in the children rated high on internalization measures. The academic scores of low internalizing children with highly elevated cortisol did not differ from those with low cortisol elevation and few inattention-internalizing problems.

Stress and Children’s Learning Contexts

The literature shows that an individual’s response to a stressor varies according to his/her perception of the degree of threat. Can the context of performance in math and testing at school be perceived as a threat to a student with MD and activate the stress response and disrupt working memory?

Children with MD may be more susceptible to experiencing stress in school because of their learning difficulties, more frequent experience with failure, and because they are placed
alongside their TA peers who do not experience the same difficulties. A number of studies have examined the self-concept of children with learning disabilities in relation to the context in which they receive their instruction and found that children with learning disabilities report lower self-concept when they receive instruction with their TA peers in their area of deficit. For example, McClain (1998) investigated the relationship between students with learning disabilities success and failure attributions, academic self-concept, anxiety, and depression, and the contextual environment in which they learned. He compared the differences between children with learning disabilities learning in resource rooms and learning in the regular classroom and found that the learning disability groups differed significantly from the regular classroom group in a number of ways. Those learning in the regular classroom had more failure attributions, poorer academic self-concept, more anxiety, and depression than those learning in a separate resource room.

Quas and Lench (2007) assessed the relationship between emotional arousal at encoding and retrieval in children, and whether the presence or lack of contextual support by a supportive versus a non-supportive interviewer affected retrieval of verbal information. These researchers used heart rate as a physiological measure of arousal. High arousal at encoding was associated with better memory for events, but high arousal at retrieval was associated with poorer verbal memory. However, when contextual support was provided, verbal recall improved. Preschoolers with high levels of cortisol have been shown to have lower effortful control, inhibitory control, and attention competency than children with lower levels of cortisol (Watamura, Donzella, Alvin, & Gunnar, 2003).

Self-Concept and Stress in Children with Learning Disabilities

As indicated above, children with learning disabilities (LD) may be more likely candidates for experiencing the general effects of stress. Chapman (1988) conducted a meta-
analysis of 20 studies to investigate the academic self-concept of TA students in comparison to children with learning disabilities. He found that TA students had a better developed academic self-concept than children with learning disability. Chapman reported a negative effect size (d) for children with learning disability of .59, .68, and 1.31 for self perceptions of academics and .42, .39 and .77 for global self-concept.

Numerous studies have found that there are no significant differences between children with learning disabilities and typically achieving children on measures of global self-worth (Bear & Minke, 1996; Bear, Minke, & Manning, 2002; Crabtree & Rutland, 2001). However, studies that have examined academic self-concept have been fairly consistent indicating that children with learning disabilty tend to score more poorly and differ significantly from their TA peers in academic self-concept in their area of deficit.

Developmental models of self-concept suggest that younger children have better self-concepts than older children. As children with learning disabilities continue in school, they increase their exposure to teacher evaluations and can develop a negative academic self-concept in their area of deficit (Wigfield & Karpathian, 1991).

Elementary children with MD rate themselves significantly lower on self-concept scales that their high achieving peers (Zeleke, 2004). Over time a low self-concept may play a role in development of the lower levels of self-efficacy, sense of coherence, positive mood, and higher levels of loneliness and negative mood, reported by children with LD (Lackaye & Margalit, 2006). The emotional states reported to be experienced by children with LD may predispose this group of children to experience stress and anxiety more than children who experience academic success. My study investigates whether grade 1 children with MD have high reactivity during working memory and math tasks by measuring the change in cortisol levels from before testing
to the testing context and how high reactivity is related to performance on the cognitive tasks believed to underlie MD.

Summary

Educational research indicates that working memory is implicated in the development of mathematical competency. Students with MD have been shown to have an impairment in working memory for numerical information and short term storage for numbers. In addition, some have shown an impairment in working memory for verbal information (working memory for words) that affects their performance in math (e.g., problem solving), and others have shown a deficit in processing speed. There is also evidence that self-reported math anxiety interferes with the core cognitive processes needed for math (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Hembree, 1990). Furthermore, when students with high math anxiety are provided with cognitive behavioural strategies to reduce their anxiety, without any additional math intervention, their performance in math improves (Hembree, 1990).

Research in cognitive psychology with adults has demonstrated that stress, particularly psychosocial stress, is associated with lower performance on tasks involving working memory (Oie et al., 2006; Schoofs, Preub, & Wolf, 2008) and on short-term storage and declarative memory retrieval tasks (Elzinga & Roelofs, 2005; Kirschbaum et al., 1996; Kuhlmann et al., 2005). Similarly, in children, it was shown that the combination of high cortisol levels and inattention and internalizing behaviours observed by teachers were associated with poorer academic reports (Jimerson et al., 2006). A moderate increase in cortisol followed by a decrease has been associated with better performance on measures of letter knowledge and executive function (Blair et al., 2005) and high arousal measured by heart rate has been associated with poorer performance on verbal retrieval tasks (Quas & Lench, 2007). The studies that have
reported low cortisol levels and learning difficulties such as in pre-term infants (Haley et al., 2006) have shown either an overall flattened cortisol response (Boyce et al., 2005) or an inverted U shaped relationship between cortisol levels and learning, with extremely low or high levels interfering with learning and moderate levels enhancing it (Lupien et al., 1999). The studies with children so far (Blair et al., 2005) indicate that a moderate elevation in arousal followed by a decrease is associated with better letter retrieval and executive function, and high arousal has been associated with an impairment in the retrieval of verbal information (Quas & Lench, 2007). For performance in math, the high arousal of the stress system may be associated with the impairment in the retrieval of semantic information contributing to impairments in working memory, or in the inhibitory processes and may slow access to representations in long term memory that result in slow processing speed.

Overview of My Study

My study had two main foci. First, it examined which of the components of working memory and processing speed are impaired in children with MD compared to TA children. Second, it examined the relationship between stress and the cognitive processing deficits of children with MD. I tested the hypothesis that high reactivity would disrupt the processes believed to underlie MD and that high reactivity would be a problem for children with MD compared to their TA peers.

This study attempted to verify the cognitive components of MD in grade 1 children, and investigated whether reactivity to stress was interfering with the processes believed to underlie MD. To accomplish these goals, grade 1 children were screened for MD and a sample of 39 students with MD were compared to a group of 44 TA students on nine subtests selected to measure working memory and processing speed in a variety of domains and math tasks. Saliva
samples were collected before and after completion of the cognitive tasks to measure the change in cortisol levels during task completion (salivary cortisol levels measure the amount of circulating plasma cortisol 30 minutes prior to the sample time). Cortisol levels were also measured on a separate day in the morning and in the afternoon to establish children’s normal circadian rhythm.

Research Questions and Hypotheses

My study examined five research questions:

1. How do grade 1 children with MD differ from their TA peers in terms of their performance on working memory, processing speed, and math tasks than their TA peers?

I tested the hypothesis that children with MD would exhibit impairment in working memory and processing speed for numerical information. We predicted that these deficits would be shown by significantly lower scores on: Working Memory for Numbers, Letter Number Sequence and Digits Backwards and on the Rapid Number Naming task. Children with MD were not expected to show impairment in short-term storage capacity (Digit Span Forward) consistent with previous findings (Passolunghi & Siegel, 2004) or on processing speed for words. There was no prediction regarding the visuospatial sketchpad because of the inconsistent findings and methodological issues in previous studies that limited the generalizability of findings.

2. How does reactivity to stress affect grade 1 children’s performance on working memory, processing speed and math tasks?

I tested the hypothesis that children with high reactivity to stress would perform significantly more poorly than children with low reactivity to stress on the working memory tasks.

3. Do children with MD differ from their TA peers in terms of their cortisol levels? Do children
with MD have higher or lower levels of reactivity or altered circadian rhythmicity compared to their TA peers?

I hypothesized that children with MD would have higher levels of reactivity during testing. This hypothesis was based on research findings with adults that have found that high reactivity impairs performance on declarative memory tasks and one study with children that found that children with a decline in cortisol levels during testing had better letter knowledge, executive function, and self regulation than those with higher levels during testing (Blair et al., 2005). I hypothesized that children with MD would have a flatter circadian rhythm compared to TA children because of research that has found that in some groups of children, children with attention and academic problems had higher overall cortisol levels across the day (Jimerson et al., 2006).

4. Does reactivity affect children in terms of their performance on working memory, processing speed, and math tasks differently in children with MD compared to their TA peers? How does reactivity affect performance within the MD group?

I predicted that reactivity would affect the performance of children with MD and TA similarly; that is, children with MD and TA children with high reactivity would perform more poorly on the working memory tasks than those with low reactivity. I also predicted that children with MD and high reactivity would perform more poorly on the working memory tasks that are found to be deficient in grade 1 children with MD.

5. How do differences in sex influence performance on working memory, processing speed, and math tasks?

Does reactivity affect girls and boys differently in terms of their performance on the working memory, processing speed, and math tasks?
I tested the hypothesis that boys and girls would perform similarly on the working memory, processing speed and math tasks. Previous research in cognitive psychology has shown that reactivity affects adult males more than females on recall tasks. Therefore, I examined whether high reactivity affects boys differently than girls. Furthermore, boys with MD and high reactivity were predicted to show the poorest outcomes.

Significance of the Study

Rapid advancements in science and technology are at the forefront of economic growth and educational systems that place an emphasis on developing mathematical competency to prepare students to participate in training and employment in science and technology. Young children who avoid math due to math anxiety or to MD limit their educational opportunities in science and technology and narrow their employment opportunities later on. By examining whether reactivity to stress contributes to impairment on the tasks believed to underlie MD, educators and researchers can focus on the development of methods of instruction and support to reduce reactivity to stress thereby reducing the number of children who might avoid math due to anxiety.

It is important to verify the cognitive processing deficits that underlie MD to fully understand the nature of MD in young children. By understanding the processes that are impaired in children with MD we can begin to identify children who may be at risk for MD and can begin to investigate possible interventions to address this problem.

If stress affects working memory, processes that are essential to the development of mathematical competency and processes that are impaired in children with MD, then attending to the stress responses of children with MD children by providing alternate methods of instruction to reduce their reactivity may improve their ability to learn.
Very few studies have investigated MD and stress in young children because of the reliability issues of self-report scales at this age (Winne et al., 2002; Winne & Perry, 2000). Physiological indicators of stress reactivity may be more reliable and can be triangulated with the information that can be gathered from self-report scales. This is the first study to examine the relationship between stress and performance on cognitive tasks associated with MD in grade 1 children by including a physiological index of reactivity to stress.

Definitions

Math disability. Children were classified as having a math disability (MD) if they scored:
a) at or below the 25th percentile on the Math Calculation, or on the Applied Problems subtests of the Woodcock Johnson Achievement Tests-III (WJ-III; Woodcock, McGrew, & Mather, 2001) and b) at or above the 25th percentile on the Work Attack, and above the 25th percentile on the Word Identification subtests of the Woodcock Johnson Achievement Tests-III (WJ-III; Woodcock, McGrew, & Mather, 2001). There was one child with a Word Identification subtest score at the 8th percentile who had been schooled in French Immersion but who obtained an average range Word Attack subtest score.

Typically achieving. A sample of 44 children with scores above the 40th percentile on all four of the screening subtests, Math Calculation, Applied Problems, Word Attack, and Word Identification, and who matched the sample with MD for sex, age, and grade were selected as the comparison group.

Stress reactivity. Stress reactivity was operationalized as the change in cortisol from T1 when no stressor was introduced, to T2 when the stressor was introduced (T2-T1). Data were log transformed and the magnitude of the log transformed difference between cortisol levels at T1 and T2 was calculated for each participant and used as an index of stress. The cortisol level
differences between T1 and T2 were grouped by quartiles to calculate low, moderate, and high reactivity categories for the effect size calculation.

Circadian rhythm. Circadian rhythm was operationalized as the magnitude of difference between morning and afternoon cortisol levels on a day when no stressor was introduced (T4-T3).
CHAPTER II: METHODOLOGY

Method

Design

The study utilized a 2 x 3 factorial design with repeated measures to examine math disability status (MD or TA). This was accompanied by a series of linear regression analyses whereby MD and TA status and cortisol reactivity were the independent/predictor variables to examine their effect on children’s performance on nine dependent/criterion variables: Working Memory for Numbers, Working Memory for Words, Digit Span Forwards, Digit Span Backwards, Rapid Number Naming, Rapid Picture Naming, Letter Number Sequence, Quantitative Concepts, and Block Rotation. My study was part of a larger program of research examining the cognitive components of math disabilities (Siegel & Ford, 2006).

Recruitment

My study was reviewed and approved by the University of British Columbia Behavioural Research Ethics Board (see Appendix B). It took place in a suburban school district of a large city in Western Canada.

My study occurred in two phases. Phase I was the administration of the screening tests. Phase II involved the data collection from the students selected as the sample for this study.

Prior to Phase I, parent consent forms were sent out to all grade 1 children in the school district asking for consent for their children to participate in the primary investigator’s study. Nine hundred and thirty-two grade 1 students from 29 different elementary schools participated in the larger study. In March through June of 2006, these children completed an initial screening battery (Phase 1), which consisted of the Math Calculation, Applied Problems, Word Identification, and Word Attack subtests of the Woodcock Johnson Achievement Tests-III (WJ-
III; Woodcock, McGrew, & Mather, 2001). Based on the results of the screening, 107 students were selected to participate in Phase II of the study, the diagnostic phase. Children were identified as having a math disability (MD) if they a) scored at or below the 25th percentile on the Math Calculation, or Applied Problems subtests of the WJ-III (Woodcock, McGrew, & Mather, 2001) and b) at or above the 25th percentile on both the Work Attack, and Word Identification subtests of the WJ-III (Woodcock, McGrew, & Mather, 2001). Children with scores above the 25th percentile on all four of the screening subtests, Math Calculation, Applied Problems, Word Attack, and Word Identification were candidates for the comparison group (TA peers). Children in the experimental and comparison groups were matched for sex, age, and grade.

A second set of consent forms was sent home with these students in the experimental and control groups to request permission to collect samples of their saliva for the current study.

Participants

Of the sample of 107 selected during screening, 83 returned signed consent forms: 39 of the children with MD and 44 of the children identified for the comparison group. These 83 children became the sample in my study. Of the 83 children who participated in my study, 49.4% were female, 10.8% were immigrants, and 10.8% reported a first language other than English. Participants ranged in age from 6.0 years to 7.3 years (M = 6.5 years).

The mean age for the 39 children classified as MD was 6.6 years. Of the 39 children who were classified as MD, 87.25% were born in Canada and reported their first language to be English, and 12.75% reported English to be their second language. Of the children who reported English to their second language, 2.6% listed their first language to be Urdu, 2.6% Korean, 2.6% Hebrew, 2.6% German, and 2.6% Chinese.
The mean age of the 44 TA children was 6.56 years. Of the 44 TA children, 90.9% of the TA students were born in Canada and reported their first language to be English and 9.1% were born outside of Canada and reported English to be their second language (ESL). Of the children who reported English as their second language, 2.3% listed their first language as Afrikaans, 2.3% Indo Iranian, 2.3% Japanese and 2.3% Korean.

Measures

Screening Phase

Four subtests were administered in the Phase I initial screening to group children as either MD or TA: Applied Problems, Math Calculation, Letter Word Identification, and Word Attack on the WJ-III (Woodcock, McGrew, & Mather, 2001).

Applied problems. The Applied Problems task (WJ-III; Woodcock, McGrew, & Mather, 2001) assessed children's ability to solve mathematical problems through the application of quantitative reasoning skills. It requires comprehension of a math problem and the ability to identify important information and then perform the calculation. Language comprehension is required, but no reading is required. For example, the child is shown a picture (e.g., a cup and an apple) and asked a question about the picture (e.g., “How many apples are there in this picture?”). Another example is the child is shown a picture (e.g., five crayons) and asked a question (e.g., “If you take away three crayons, how many would you have left?”). The child must determine the appropriate procedure to solve the problem and state the solution.

Math calculation. This is an untimed subtest from the WJ-III (Woodcock, McGrew & Mather, 2001) that measures children's math achievement by assessing their ability to perform mathematical computations. The initial items involve writing single numbers and subsequent
items require addition, subtraction multiplication and division. For example: $1 + 3, 7 - 3, 8 + 9, 18 - 9$.

Letter-word identification. The Letter-Word Identification task (WJ-III; Woodcock, McGrew, & Mather, 2001) was employed to test the child's ability to decode words presented in isolation. The subtest requires identifying and reading isolated letters and words of increasing difficulty. For example: is, the, and, from, keep, their.

Word attack. Word Attack (WJ-III; Woodcock, McGrew, & Mather, 2001) is a task that requires children to pronounce phonetically regular pseudowords. For example: nat, ib, fim, jop, floxy.

Classification of math disability. Children were identified as MD if they scored at or below the 25th percentile on either the Math Calculation or the Applied Problems subtests and above the 25th percentile on Word Identification and Word Attack subtests of the Woodcock Johnson Tests of Achievement WJ-III ACH (Woodcock, McGrew, & Mather, 2001). Children who scored below the 25th percentile on either of the reading subtests were excluded from the MD group and the TA group. Children with scores above the 40th percentile on all four of the screening subtests and who matched the MD group in terms of gender, age, grade, language and school were selected as the comparison group. Children with hearing or visual impairment, intellectual disability, and ministry identified behavioural or emotional disturbance were not included in the study.

Diagnostic Phase

Measures of working memory were assessed in both the numerical and linguistic domains: Working Memory for Numbers and Working Memory for Words, Digits Backwards and Letter Number Sequence. The phonological loop (short term memory storage) was measured
by Digit Span Forward. Processing Speed was measured by the Rapid Number Naming and Rapid Picture Naming tasks. Visuospatial manipulation was measured by the Block Rotation task and math performance by Quantitative Concepts.

Working memory for numbers. The Working Memory for Numbers task (counting span) is based on a procedure developed by Case et al., (1982), and has been used as an experimental task in the literature to assess working memory or visual counting memory under memory load. The pattern used for the stimuli was a field of yellow and blue dots that are randomly placed on 30 x 20 cm white index cards. The researcher states, "I want you to count the yellow dots out loud. Try not to pay attention to the blue dots. Touch each yellow dot as you count. When you are finished counting I am going to turn the card over and I want you to remember the number of yellow dots that you just counted." After the child has finished counting and the card has been turned over the researcher asks, "How many yellow dots were there?" Then the researcher states, "Now we are going to try the same thing with two cards." The goal of the task is for the student to remember the number of yellow dots in each set of cards in levels of two, three, four, and five and then remember the counts for each set in the correct order. The task ceiling was reached and the administration terminated when the student failed all items in a set.

Working memory for words. Working Memory for Words, referred to as listening span in the literature (see Appendix A), was developed by Siegel and Ryan (1989), and modified from the procedure developed by Daneman and Carpenter (1980). The researcher stated, "I am going to say some sentences and the last word in each sentence will be missing. I want you to tell me what you think the last word should be. Let’s try one. For breakfast the little girl had orange ______. Now I am going to read two sentences. After each sentence, I want you to tell me the word that should go at the end of the sentence. When I finish the two sentences, I want you to
tell me the two words that you said for the end of each sentence.” The participant listened to the researcher read aloud sets of short sentences in which the final word is missing (e.g., “In a baseball game the pitcher throws the _____”). When all sentences in a set were read and completed by the participants, the participants repeated the words that completed the sentences in the correct order. The response was considered correct if the participants repeated the words in the right order. The test consists of 12 sets of sentences of increasing difficulty. The test began with two sets of two sentences followed by three sets of three, four, and five sentences. Two practice sets were presented to ensure that the participants understood the task. Testing stopped when the participant failed all items at a level.


Digit span. Digit Span (WISC-IV; Wechsler, 2003) is a subtest composed of two subtests, Digit Span Forward, and Digit Span Backward. Digit Span Forward was included as a measure of the storage capacity of the phonological loop. Digit Span Backward was included as a dual processing task because of the requirement to remember the numbers and sequence them in reverse order.

Digit span forward. Digit Span Forward (WISC-IV; Wechsler, 2003) is a simple span task measuring phonological storage or short-term storage for small amounts of information. The child heard a list of digits at the rate of one digit per second. After hearing the series of numbers, the child was required to repeat the digits in order of presentation. There are a total of eight items with two trials in each for a possible maximum score of 16. The discontinue rule or ceiling level
was reached after scores of 0 were obtained on both trials of an item. The test score is the total number of correct answers at maximum. The split half reliability for Digit Span is .87.

Digit span backward. The Digit Span Backward (WISC-IV; Wechsler, 2003) is a complex working memory span task where the child heard digits read out at the rate of one per second. There are a total of 8 items with two trials. At the end of each list of numbers, the child was required to provide the numbers back in reverse order. One practice item was presented to ensure that the participants understood the reversal requirement. There were 8 levels with 2 items each for a maximum possible raw score of 16. The discontinue or ceiling rule is a score of 0 on both trials of an item. The split half reliability for Digit Span is .87.

Letter number sequence. Letter Number Sequence (WISC-IV; Wechsler, 2003) was included as a dual processing task involving the storage and processing manipulation that required the child to store a set of numbers and letters and manipulate them into a sequence. It is a complex span task measuring working memory for numbers and letters. The examiner read a sequence of numbers and letters and the participants were required to remember the numbers and letters (storage) and repeat back the numbers in ascending order and the letters into alphabetical order (processing). There were two practice items with one number and one letter to ensure that the participants understood. There were 10 levels with 3 items in each, for a total possible raw score of 30. The raw score was the total number of items correct. The discontinue rule or ceiling level was reached after scores of 0 were obtained on all three trials of an item. The reliability for Letter Number Sequence is .90.

Rapid picture naming. Rapid Picture Naming (WJ III COG; Woodcock, McGrew, & Mather, 2001) is a measure of processing speed for naming common nouns. Children began with a sample item where they practice naming 10 different items as quickly as they can.
Children were presented with a page with pictures of common items. The child was asked to name the pictures as quickly as they can within two minutes. The score is the number of pictures named in two minutes. The total number of items is 120. The split half reliability of Rapid Picture Naming is .98.

Rapid number naming. Rapid Number Naming, required children to name a series of single digit numbers as quickly as possible. The children were required to name individual numbers (one to nine) presented in a random order with five rows and five columns (25 items). The score is recorded as the time in seconds it takes to name all the numbers.

Block rotation. Block Rotation is a standardized subtest from the Woodcock Johnson Test of Cognitive Abilities (WJ III COG; Woodcock, McGrew, & Mather, 2001) where the participant was required to solve mental rotation tasks. The child was shown a drawing with a multiple choice of five drawings below it. Two of the drawings in the multiple-choice format are the same as the item presented. The examiner pointed to the drawing and stated, “Look at this drawing, it looks just like this drawing and this drawing.” The child was then presented with series of pictures of three-dimensional visual patterns and was asked to select from a multiple choice format two three-dimensional pictures that matched the stimulus, but have been changed in spatial orientation. The total number of items is 24. Reliability estimates were not reported in the technical manual.

Number series. The Number Series subtest (WJ III COG; Woodcock, McGrew, & Mather, 2001) measures mathematics knowledge and quantitative reasoning. The child was presented with a series of numbers with one number missing in the set. The child provided the number that completes the sequence. For example: 2,4, __, 8 ; __, 3,5,7 ; 6,5,4, __ ; 2,4,6, __.
Quantitative concepts. Quantitative concepts (WJ III COG; Woodcock, McGrew, & Mather, 2001) provided a measure of children’s knowledge of cardinal ordering, counting, sequencing, associative principles, and signs of operation. The child is presented with questions read by the examiner, some questions are accompanied by visual stimuli and others are not. For example, in the first item the child is presented with a picture of two dogs and the examiner reads, “How many dogs are there?” In another question the examiner says, “Listen. What number comes between three and five?” In another question the examiner asks “When you count what number comes right before eight?” or “When you count what number comes right after 37?” There are 34 items and the ceiling level is reached after a child has received scores of 0 on four consecutive items.

Saliva Collection

Cortisol was analyzed from saliva samples. Saliva sampling is efficient, reliable and relatively unobtrusive. Children placed half-inch cotton rolls in their mouths to chew for about 1 minute or until saturated. A piece of dental floss was attached to the cotton roll to prevent accidental swallowing or choking. The entire procedure took approximately five minutes. The wet cotton roll was collected and placed into a labelled vial for storage at -20 C until assayed.

Salivary cortisol assay. The expanded range high sensitivity salivary cortisol enzyme immunoassay kit (Salimetrics LLC Expanded Range High Sensitivity Salivary Cortisol Enzyme Immunoassay Kit, Philadelphia, PA) was created to measure salivary cortisol for research with humans. It is measures cortisol levels from 25 ug/dL (micrograms per decilitre) of salvia per test. This assay is designed to be valid in experimental situations where interference may occur through collection techniques that affect pH such as consumption of food or drink. Assays were done in the laboratory of Dr. Joanne Weinberg at the University of British Columbia.
Cortisol reactivity. The difference between cortisol levels at T1 and T2 (T2-T1) was used as the measure of reactivity for each participant. The reactivity index was divided into quartiles as the categorical index marker for stress (high, moderate and low) consistent with previous studies (Boyce et al., 2005; Kagan, Reznick, & Snidman, 1997). The categorical index marker of stress was used to interpret the magnitude of the effect of stress reactivity on performance (effect size calculation). Cortisol level differences from T1 to T2 that were equal to or above the top quartile were classified as high, those equal to or below the first quartile were classified as low and cortisol level increases above the first and below the third quartile were classified as moderate reactivity. An example of the types of values associated with a participant from each of the categories follows: low reactivity = -.4059, moderate reactivity = .0686, and high reactivity = .2640.

Circadian rhythm. The change from T3 to T4 was computed by subtracting the T3 values from the T4 values (T4-T3 = decrease from AM to PM) as an index of the circadian rhythm for each participant.

Procedures

On Day 1 of my study at 9:00 A.M., research assistants obtained the parent consent forms from the school secretary and checked to confirm that parent consent forms had been completed and signed.

Two children were tested each day with the testing divided into two 40-minute sessions for each child, 40 minutes in the morning for the larger research project, and 40 minutes in the afternoon for this research project. Students were called individually from their classrooms by the research assistants and taken to private rooms in the elementary schools. The research
assistants read an introductory preamble that explained to children what they would be doing, the length of time was required, and why they had been chosen for the study.

You have been selected to do some tasks this morning and this afternoon that are kind of fun and interesting. It will take about 40 minutes each time. You are helping the Math Research Team find out how children in Grade 1 learn best.

The research assistants read the Child Assent form (Appendix D) to describe the testing and to explain how a saliva sample would be collected. Verbal assent was obtained from children under the age of 7 and children printed their name to indicate consent if the child was 7 years of age and older.

On Day 1 at 1:00 P.M., students were called individually by the research assistants from their classrooms and taken to an individual room for the second set of tests, which involved the testing for this project. Two children were tested each afternoon. The first student started the testing process at 1:00 PM and the second at 1:40 PM. The tasks were administered in the following order: saliva sample T1, Working Memory for Numbers, Working Memory for Words, Digit Span (forward and backward) (WISC-IV; Wechsler, 2003), Letter Number Sequence (WISC-IV; Wechsler, 2003), Quantitative Concepts (WJ-III Achievement; Woodcock, McGrew, & Mather, 2001), Rapid Picture Naming (WJ-III; Woodcock, McGrew, & Mather, 2001), Block Rotation (WJ-III; Woodcock, McGrew, & Mather, 2001). Saliva sample T2 was collected 30 minutes from the start of testing. Thus saliva was collected from the children on Day 1, at 1:00 PM or at 1:40 PM (pre-test), and (post-task), at 30 minutes from the start of testing in accordance with Dickerson and Kememy’s (2006) findings that cortisol collection that occurs 21-40 minutes from the start of the stressor reflects the largest response. Also stress studies have found the stress response is easier to detect in the afternoon than in the morning when cortisol levels are naturally elevated.
Salivary cortisol levels measured 30 minutes post task are an accurate physiological measure of circulating cortisol levels during the task (Kirschbaum & Hellhammer, 2000). On Day 2, a day without testing, research assistants returned to the school; saliva sample T3 was collected between 9 and 9:30 AM and saliva sample T4 was collected at 2:45 PM. These samples were taken as an estimate of children’s normal circadian rhythm (basal hormone levels in the absence of a stressor).
CHAPTER III: RESULTS

Results

My study had two main questions: to examine whether and how (a) grade 1 children with MD perform differently on working memory and processing speed tasks compared with their TA peers; and (b) children who experience stress while performing working memory and processing speed tasks perform more poorly than children who do not. Particularly, I was interested in whether and how reactivity to stress exacerbates the processing problems believed to underlie MD.

The five research questions were addressed by the statistical analyses described below:

1. How do grade 1 children with MD differ in terms of their performance on working memory, processing speed, and math tasks compared with their TA peers?

To answer the first research question, a series of univariate analyses of variance (ANOVAs) were carried out. More clearly, ANOVAs were conducted to examine differences in performance between children with MD and their TA peers on the nine dependent variables. The ANOVA was calculated for MD and TA, alpha was set at p < .05 for H0: μ1 = μ2. A Bonferroni correction was applied to adjust for family wise Type I error and significance was accepted at p < .005 (.05/9 =.005).

2. How does reactivity to stress affect grade 1 children’s performance on working memory, processing speed and math tasks?

The second research question was answered by employing linear regression analyses using MD and TA and reactivity as the predictors to assess the contribution of reactivity to performance on the nine tasks.
3. Do children with MD differ from their TA peers in terms of their cortisol levels? Do children with MD have higher or lower levels of reactivity or circadian rhythm?

This research question was answered by conducting a series of independent t-tests. Specifically, cortisol levels at T1, T2, T3, and T4, for reactivity, and for circadian rhythm were conducted to examine differences in mean cortisol levels by MD and TA.

4. Does reactivity affect children with MD and TA differently in terms of their performance on working memory, processing speed, and math tasks?

In the fourth research question the interaction between MD/TA and reactivity was examined to determine whether reactivity affected children with MD differently from TA children.

How does reactivity affect performance within the MD group?

Independent t-tests were computed for the children with MD compared by high and low reactivity on the tasks that were impaired in children with MD. Alpha was set at p < .05 for H0: μ1 = μ2. A Bonferroni correction was applied to adjust for family wise Type I error and significance was accepted at p < .01 (.05/5 = .01).

5. How does sex influence performance on working memory, processing speed and math tasks?

ANOVA's were employed to examine the sex differences, if any on the nine tasks. Bonferroni corrections were applied to control for family wise type I error.

Does reactivity affect girls and boys differently in terms of their performance on the working memory, processing speed, and math tasks?

The interaction for sex and reactivity was examined to determine whether reactivity affected boys differently than girls on the performance tasks.
Preliminary Analyses

Data Inspection

Assumptions of normality, homogeneity of variance, and independence were met. All dependent variables demonstrated reasonably normal distributions, Q-Q plots were examined and skewness was not extreme. The ANOVA for MD and TA was followed by effect size calculations to illustrate the magnitude of the mean differences between the children with MD and TA.

The cortisol data were positively skewed which is typical for cortisol data; accordingly, as noted, the data were log transformed. Log transformation restores normality to the data and reduces the leverage of children with large absolute values which would have had significant influence on the regression. The linear regression assumes that the relationship between the performance scores and reactivity is linear after adjusting for MD/TA. Linearity for reactivity was assumed based on examination of the scatterplots for the dependent variables. The linear regression was conducted for log transformed reactivity adjusted for MD and TA and alpha was set at \((p < .05)\) for: \(H_0: \beta \text{ (slope)} = 0\).

Effect Size

Effect sizes for all comparisons were calculated by comparing the mean difference in performance between low and high reactivity groups divided by the pooled SD for each of the tasks to demonstrate the magnitude of differences in performance on the nine tasks. With respect to effect sizes, Cohen's \(d\), corrected for bias with Hedge's \(g\) (1985), is reported. According to Cohen (1988), an effect size of 0.20 is small, 0.50 is moderate, and 0.80 is classified as large. The results of the analyses for each research question are presented below.
How Do Grade 1 Children with MD Differ in Terms of their Performance on Working Memory,
Processing Speed, and Math Tasks from their TA Peers?

Table 3.1 displays the means and standard deviations for the tasks involving working
memory, processing speed, and math concepts along with the ANOVA results and effect sizes
for these tasks. The results for each task are discussed below.

Table 3.1

Univariate Tests of Significance, Effect Size, and Descriptive Statistics for the Cognitive Tasks.

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>MD (n = 39)</th>
<th></th>
<th>TA (n = 44)</th>
<th></th>
<th>F</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working memory for numbers</td>
<td>3.28</td>
<td>1.61</td>
<td>4.05</td>
<td>1.67</td>
<td>4.48</td>
<td>-.46</td>
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<td>Working memory for words</td>
<td>1.87</td>
<td>1.45</td>
<td>2.52</td>
<td>1.30</td>
<td>4.62</td>
<td>-.47</td>
</tr>
<tr>
<td>Digit span forwards</td>
<td>6.97</td>
<td>1.87</td>
<td>7.77</td>
<td>1.61</td>
<td>4.36</td>
<td>-.45</td>
</tr>
<tr>
<td>Digit span backwards</td>
<td>4.59</td>
<td>1.39</td>
<td>5.20</td>
<td>1.62</td>
<td>3.39</td>
<td>-.40</td>
</tr>
<tr>
<td>Rapid number naming</td>
<td>17.92</td>
<td>6.29</td>
<td>15.07</td>
<td>3.70</td>
<td>6.52</td>
<td>-.55</td>
</tr>
<tr>
<td>Rapid picture naming</td>
<td>99.62</td>
<td>14.06</td>
<td>105.50</td>
<td>13.90</td>
<td>3.82</td>
<td>-.42</td>
</tr>
<tr>
<td>Letter number sequence</td>
<td>7.23</td>
<td>2.70</td>
<td>9.61</td>
<td>3.12</td>
<td>13.67*</td>
<td>-.77</td>
</tr>
<tr>
<td>Quantitative concepts</td>
<td>94.78</td>
<td>8.93</td>
<td>110.18</td>
<td>13.71</td>
<td>35.62*</td>
<td>-1.30</td>
</tr>
<tr>
<td>Block rotation</td>
<td>98.87</td>
<td>17.43</td>
<td>105.27</td>
<td>16.72</td>
<td>2.91</td>
<td>-.37</td>
</tr>
</tbody>
</table>

Note: Negative d indicates that children with MD obtained lower performance than TA children. p < .05. *
Working Memory

Working memory was assessed by the following tasks: Working Memory for Numbers, Working Memory for Words, Letter Number Sequence, and Digits Backwards.

Working memory for numbers. The ANOVA results indicated a non significant difference between MD and TA children's performance on tasks involving Working Memory for Numbers, $F(1, 81) = 4.481, p = .037, d = -.46$. Specifically, children with MD exhibited a non-significant impairment in performance on working memory for numerical information compared to their TA peers. These findings are inconsistent with previous research (Hitch & McAuley, 1991; McLean & Hitch, 1999; Siegel & Ryan, 1989). The lack of significance of findings for this task may be explained by the differences in the ages of the samples studied and some of the children the MD sample may have been false positive or children with low math achievement rather than "true" MD. The number of comparisons and low statistical power of this analysis also contributed to the non significant findings.

Working memory for words. The ANOVA results indicated a non significant difference in performance between children with MD and their TA peers on tasks involving Working Memory for Words, $F(1, 81) = 4.628, p = .034, d = -.47$, corresponding to a small effect size. The results indicated that grade 1 children with MD were not impaired in working memory for verbal information in comparison to TA children. There have been conflicting findings with regard to whether or not working memory for words is impaired in children with MD. Some researchers have argued that there is little evidence of non numerical semantic deficits in children with MD and view the processing of numerical information as operating outside the semantic memory system (Landerl et al., 2004). Indeed, some researchers have found that
children with MD have impairments in working memory for numerical information only (Hitch & McAuley, 1991; McLean & Hitch, 1999; Siegel & Ryan, 1989).

The non significant findings for this task are not consistent with research that has found evidence of impairments in both working memory for words and numbers (Barrouillet et al., 1997; Geary et al., 2000; Geary et al., 2007; Jordan & Montani, 1997; Passolunghi & Siegel, 2004), however the effect size suggests functional impairment for children with MD compared to their TA peers for this task. The multiple comparisons reduced the power of this analysis and contributed to non significant findings.

Letter number sequence. The ANOVA results indicated a statistically significant difference between children with MD and their TA peers on the Letter Number Sequence task and the magnitude of the effect was moderate, F (1, 81) = 13.675, p < .01, d = -.77. These findings are consistent with previous research that has found a working memory deficit for numerical tasks or tasks involving counting type procedures. This finding supports the hypothesis that children with MD exhibit significant impairments on working memory tasks involving numbers and letters compared to TA children.

Digit span backwards. The ANOVA results indicated non significant differences between children with MD and their TA peers on the Digit Span Backwards task, F (1, 81) = 3.392, p=.069, d = -.40. The effect size for MD was small. These findings are consistent with one study that did not find differences between children with MD and TA children on simple span tasks for numbers (Temple & Sherwood, 2001); however, the findings are inconsistent with other studies that have found Digit Span Backwards to be impaired in children with MD. Passolunghi and Siegel (2004) found that grade 5 children with MD were impaired on the Digit Span Backwards task and Geary et al., (2007) also found evidence of impairment on the Digit Span Backwards
task in kindergarten and grade 1 children with severe MD (scores on math achievement tests below 16th percentile). The differences between this study and those that have found significance on this task (Geary et al., 2007) may be the use of more restrictive cut-off scores for inclusion in the MD group identifying children with more severe MD and the presence of false positives in the MD sample. Also the multiple comparisons and low power may have contributed to the lack of statistical significance.

Short-Term Storage

Short-term storage capacity was assessed by the Digit Span Forward task.

Digit span forward. The ANOVA results indicated a non significant difference between children with MD and their TA peers on the Digit Span Forward task, $F (1, 81) = 4.362, \ p = .04, \ d = -.45$. Grade 1 children with MD did not exhibit significantly lower performance compared than their TA peers on this task and the effect size for this difference was small. These findings are consistent with the literature that has not found an impairment in short-term memory (Swanson & Jerman, 2006; Passolunghi & Siegel, 2004) and inconsistent with the studies that have found an impairment in short term storage (Hitch & McAuley, 1991; McLean & Hitch, 1999). The effect size for this task suggests that there may be functional impairment, or smaller capacity for short term storage for children with MD compared to their TA peers. The different findings across studies may reflect differences in the ages of the samples studied, in the composition of the MD samples (inclusion of two types of MD) and the presence of false positives in the MD sample. The multiple comparisons and low power may have contributed to the lack of statistical significance.
Processing Speed

Processing speed for numbers was assessed by Rapid Number Naming and processing speed for words was assessed by Rapid Picture Naming.

Processing speed for numbers. The ANOVA results indicated a non significant difference between children with MD and their TA peers on Processing Speed for Numbers, $F(1,81) = 6.52, p = .013, d = -.55$, corresponding to a moderate effect size. Specifically, children with MD did not exhibit impairment in performance on processing speed for numbers compared to their typically achieving peers, however the effect size for this was moderate. These findings are not consistent with the hypothesis that children with MD would exhibit impairment in processing speed for numbers or with the literature that has found an impairment in processing speed for numbers (Bull & Johnson, 1997; Geary et al., 2007; Hitch & McAuley, 1991). The moderate effect size ($d = -.55$) suggests that processing speed for numbers is less efficient in children with MD, but tests did not reach statistical significance. Different findings across studies may reflect the differences in the ages of the MD samples studied and the possibility of false positives within the grade 1 MD group (Geary et al., 2000; Passolunghi & Siegel, 2004).

Processing speed for words. The ANOVA results indicated a statistically non significant difference between children with MD and their TA peers on Rapid Picture Naming, $F(1,81) = 3.826, p = .054, d = -.42$. These findings are consistent with previous research that has not found an impairment in processing speed for words, (Geary et al., 2000; Passolunghi & Siegel, 2004) Findings confirm the hypothesis that children with MD would not exhibit significant differences on this task, and the effect size was small although children with MD were less efficient at this task.
Quantitative Concepts

The ANOVA results indicated a statistically significant difference between children with MD and their TA peers on Quantitative Concepts, $F(1,81) = 35.627, p < .01, d = -1.30$, corresponding to a large effect size. The findings are consistent with the literature that has found that children with MD perform more poorly on tasks assessing mathematics knowledge, counting, cardinal ordering and associative principles. These findings confirm the hypothesis that children with MD would obtain significantly lower means than the TA children for this task.

Spatial Rotation

Visual spatial processing was assessed by the Block Rotation task. The ANOVA results indicate no statistically significant differences between children with MD and their TA peers on Block Rotation, $F(1,81) = 2.91, p = .092, d = .37$. It is difficult to discuss these findings in relation to the existing literature due to the wide variability of the types of tasks used to assess visual spatial ability in the literature. However, the findings of this study are consistent with the previous research that has found no differences between children with MD and TA on visual spatial tasks (Geary et al., 2000; Landerl et al., 2001). However, these studies used mapping and directions, and mazes, as measures of visual spatial ability, subtests which require visual motor skills confounding motor skills with visual spatial ability, whereas Block Rotation does not require visual motor skills. Other studies have found impairment on visual spatial tasks (Geary et al., 2007; Keeler & Swanson, 2001; Mclean & Hitch, 1999; Rourke, 1993; Swanson & Jerman, 2006), but again the tasks used to assess visual spatial ability were variable, confounding visual motor skills with visual spatial ability. In this study, visual spatial ability was isolated from visual motor ability and no significant differences between grade 1 children with MD and TA children were found.
In summary, the statistical analyses indicated that children with MD differed significantly from their TA peers on working memory tasks for letters and numbers and math tasks and these findings are consistent with the literature. The lack of statistical significance on working memory for numbers, working memory for words and process speed for numbers is inconsistent with the literature, and with this study’s hypotheses. The effect sizes for group membership (MD) for working memory for numbers, working memory for words and process speed for numbers suggests that these are tasks that children with MD are functionally impaired on compared to their TA peers. The possibility of false positives in the MD group, the multiple comparisons and subsequent conservative Bonferroni adjustments lowered the power of the analyses and increased the possibility of accepting a null hypothesis (type II error) when true differences may exist. The effect sizes suggested less efficient performance for children with MD compared to their TA peers on memory for numbers and words, and in their processing speed for numbers and words.

How Does Reactivity Affect Grade 1 Children’s Performance on Working Memory, Processing Speed and Math Tasks?

To assess the contribution of reactivity to performance on the nine cognitive tasks, reactivity was calculated from the log transformed difference in cortisol levels from T2 to T1 (T2-T1). A linear relationship between reactivity and performance on the tasks was assumed based on examination of the scatterplots. A linear regression analyses was conducted for reactivity and MD and TA to determine if reactivity predicted performance on the nine tasks without the influence of MD/TA. The regression results are presented in Table 3.2.
Table 3.2

Linear Regression Results for Reactivity Adjusted for MD and TA for the Cognitive Tasks

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>β</th>
<th>SE</th>
<th>Beta</th>
<th>t</th>
<th>p</th>
<th>R²</th>
<th>R²*</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working memory</td>
<td>-2.519</td>
<td>.973</td>
<td>-.271</td>
<td>-2.589</td>
<td>.011*</td>
<td>.074</td>
<td>.126</td>
<td>-.66</td>
</tr>
<tr>
<td>for numbers</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working memory</td>
<td>-1.831</td>
<td>.825</td>
<td>-.234</td>
<td>-2.220</td>
<td>.029*</td>
<td>.058</td>
<td>.109</td>
<td>-.88</td>
</tr>
<tr>
<td>for words</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digit span forwards</td>
<td>-.859</td>
<td>1.069</td>
<td>-.087</td>
<td>-.803</td>
<td>.424</td>
<td>.009</td>
<td>.059</td>
<td>-.02</td>
</tr>
<tr>
<td>Digit span</td>
<td>.231</td>
<td>.937</td>
<td>.027</td>
<td>.246</td>
<td>.806</td>
<td>.001</td>
<td>.041</td>
<td>-.14</td>
</tr>
<tr>
<td>backwards</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapid number</td>
<td>3.483</td>
<td>3.116</td>
<td>.119</td>
<td>1.118</td>
<td>.267</td>
<td>.015</td>
<td>.089</td>
<td>.09</td>
</tr>
<tr>
<td>naming</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rapid picture</td>
<td>16.642</td>
<td>8.430</td>
<td>-.211</td>
<td>-1.974</td>
<td>.052</td>
<td>.049</td>
<td>.089</td>
<td>-.57</td>
</tr>
<tr>
<td>naming</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Letter number</td>
<td>-2.282</td>
<td>1.792</td>
<td>-.130</td>
<td>-1.274</td>
<td>.207</td>
<td>.021</td>
<td>.161</td>
<td>-.38</td>
</tr>
<tr>
<td>sequence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantitative</td>
<td>-18.074</td>
<td>6.952</td>
<td>-.233</td>
<td>-2.600</td>
<td>.011*</td>
<td>.064</td>
<td>.360</td>
<td>-.55</td>
</tr>
<tr>
<td>concepts</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Block rotation</td>
<td>-3.156</td>
<td>10.533</td>
<td>-.033</td>
<td>-.300</td>
<td>.765</td>
<td>.002</td>
<td>.036</td>
<td>.08</td>
</tr>
</tbody>
</table>

Note: d was calculated for high reactivity compared to low reactivity categories. A negative effect size indicates that the low reactivity group performed better than the high reactivity group. The effect size is the difference in standard deviation in mean score according to group membership. For example, WMN (d = .64) indicates that the high reactivity mean score was .64 of a standard deviation below the mean of the low reactivity group. R² indicates the percentage of variance in scores accounted for by reactivity after controlling for MD/TA. R²* indicates the percentage of variance in scores accounted by both MD/TA and reactivity. *p < .05.

To interpret the meaning of results, a significant t-test indicates that the slope for reactivity is significantly different from 0, and therefore the null hypothesis can be rejected; i.e., reactivity contributes significantly to performance on the task. The beta value is an effect size that accounts for a unit of change in the predictor (reactivity), the score on the dependent
variable (Working Memory for Numbers) increases by the beta value. A significant negative beta value indicates that for every unit that reactivity increases the score on the task decreases by the value of beta.

The R² is an effect size that indicates the amount of variance that is explained by the predictors (reactivity and MD/TA). The first R² reported is for reactivity and the second is for the influence of both MD/TA and reactivity. These values indicate the amount of variance in performance explained by reactivity and by both MD/TA and reactivity. The effect size (Cohen’s d) provides an indication of the magnitude of the effect of group membership in the high or low reactivity group.

The value of the effect size is the standardized difference between means (M1-M2 divided by the pooled standard deviation corrected for bias using Hedge’s g). Cohen (1988) defined an effect size of .2 as small, .5 as medium, and .8 as large. A negative effect size indicates that the high reactivity group performed more poorly than the low reactivity group.

The categories of low, moderate, and high reactivity were calculated to provide effect sizes for the interpretation of reactivity and the cognitive tasks. The effect size was calculated by dividing the difference in means of the high and low reactivity groups by the pooled standard deviation.

Of the moderate group 17 or 20.5% were MD and 24 or 28.9% were TA. Those students with increases in cortisol from T1 to T2 equal to or greater than the fourth quartile (.0985 to .5934 or .0186 to .2179 ug/dL) were classified as the high group (n = 21 or 25.3% of the sample). Of the high group 11 or 13.3% were MD and 10 or 12.0% were TA. Effect sizes were calculated for the cognitive tasks by high to low reactivity categories to provide meaningful
interpretation of reactivity and performance on the tasks. Table 3.3 provides the frequency percentages of the whole sample for each of the cortisol reactivity groups by MD and TA.

Table 3.3

<table>
<thead>
<tr>
<th>Cortisol reactivity</th>
<th>Low (-.4059 to -.1357)</th>
<th>Moderate (-.1269 to .0921)</th>
<th>High (.0985 to .5934)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1 to T2 MD</td>
<td>11 (13.3%)</td>
<td>17 (20.5%)</td>
<td>11 (13.3%)</td>
</tr>
<tr>
<td>TA</td>
<td>10 (12.0%)</td>
<td>24 (28.9%)</td>
<td>10 (12.0%)</td>
</tr>
</tbody>
</table>

Table 3.4 provides the descriptive statistics for the performance tasks by reactivity groups, low, moderate, and high and the effect sizes for the mean differences between the high to low reactivity.

Working Memory

Working memory for numbers. The regression results indicated that reactivity statistically significantly predicted performance on the Working Memory for Numbers task $\beta = -2.519$, $t(83) = -2.589$, $p = .011$. The negative $\beta$ and significant t-test indicated that the slope $\neq 0$ for reactivity, and therefore the null hypothesis can be rejected. For every unit of reactivity increase, performance on the Working Memory for Numbers decreased by the value of Beta. The effect size for mean differences between the high reactivity and low reactivity children was moderate ($d = -.64$). The negative moderate effect size indicates that the high reactivity group performed .64 of a standard deviation lower than the mean of those in the low reactivity group. The $R^2$ for reactivity indicates the amount of variance in working memory scores that is explained by reactivity. The $R^2$ for MD/TA and reactivity is an indication of the amount of variance in Working Memory for Numbers that is accounted for by both independent variables.
For Working Memory for Numbers, reactivity explained 7% of the variance in performance on the memory for numbers task and almost 13% could be explained by both math disability and reactivity ($R^2$ for MD and TA = .052 and $R^2$ for MD/TA and Reactivity = .126).

Table 3.4
Descriptive Statistics for Performance Tasks and Reactivity Categories and Effect Size

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>M</td>
</tr>
<tr>
<td>Working memory for numbers</td>
<td>4.33</td>
<td>1.65</td>
<td>3.66</td>
</tr>
<tr>
<td>Working memory for words</td>
<td>2.62</td>
<td>1.28</td>
<td>2.37</td>
</tr>
<tr>
<td>Digit span forwards</td>
<td>7.33</td>
<td>1.46</td>
<td>7.44</td>
</tr>
<tr>
<td>Digit span backwards</td>
<td>4.95</td>
<td>1.02</td>
<td>4.78</td>
</tr>
<tr>
<td>Rapid number naming</td>
<td>16.52</td>
<td>4.57</td>
<td>16.54</td>
</tr>
<tr>
<td>Rapid picture naming</td>
<td>107.52</td>
<td>10.58</td>
<td>102.22</td>
</tr>
<tr>
<td>Letter number sequence</td>
<td>9.19</td>
<td>2.92</td>
<td>8.46</td>
</tr>
<tr>
<td>Quantitative concepts</td>
<td>108.10</td>
<td>15.01</td>
<td>101.85</td>
</tr>
<tr>
<td>Block rotation</td>
<td>102.10</td>
<td>15.45</td>
<td>103.15</td>
</tr>
</tbody>
</table>

Note. d is standardized mean difference for the high to low reactivity categories. *p < .05.

Working memory for words. The regression results indicated that reactivity statistically significantly predicted performance on the Working Memory for Words task: $\beta = -1.831$, $t (83) = -2.22$, $p = .029$. The effect size for reactivity for the Working Memory for Words task was large; the children with high reactivity obtained lower scores than the children with low reactivity ($d = -.88$). Reactivity explained almost 6% of the variance in scores for the working memory for
words task and MD and reactivity explained almost 11% of the variance for this task ($R^2$ for
MD/TA = .05 and for MD/TA and reactivity $R^2 = .109$).

Digit span backwards. The regression results indicated that reactivity did not significantly
predict performance on the Digits Backwards task: $\beta = .231$, $t (83) = .246$, ns. The effect size for
high and low reactivity for this task was small ($d = -.14$); the children with high reactivity
obtained lower scores than the low reactivity group. Reactivity accounted for .001% of the
variance on the Digits Backwards task ($R^2$ for MD/TA=.04; and $R^2$ with MD/TA and reactivity
=.04).

Letter number sequence. The regression results were not significant for reactivity and
performance on the Letter Number Sequence task $\beta = -2.282$, $t (83) = -1.274$, ns. The effect size for
mean differences in performance by high and low reactivity was small ($d = -.38$); the students
with high reactivity obtained lower scores than those with low reactivity. Reactivity explained
about 2% of the variance on the Letter Number Sequence task and 16% of the variance on this
task could be explained by MD/TA and reactivity (for MD/TA $R^2 = .14$; MD/TA and reactivity $R^2 = .161$).

Processing Speed

Processing speed for numbers. The regression results indicated performance was not
significantly predicted by reactivity on Processing Speed for Numbers $\beta = 3.483$, $t (83) = -1.118$,
ns. The effect size for this was small ($d = -.09$). Reactivity explained only 1% of the variance on
the Processing Speed for Numbers task. Approximately 9% of the variance in performance on
the Rapid Number Naming task was accounted for by MD/TA and reactivity (MD/TA $R^2 = .074$;
MD/TA and reactivity $R^2 = .089$).
Processing speed for words. The regression results indicated that performance was not significantly predicted by reactivity on the Processing Speed for Words task $\beta = -16.642$, $t(83) = -1.974$, ns. The effect size for high to low reactivity was moderate ($d = -.57$). Reactivity explained approximately 5% of the variance in performance on the Rapid Picture Naming task. Approximately 9% of the variance in scores was explained by MD/TA and reactivity ($R^2 = .045$; MD/TA and reactivity $R^2 = .089$).

Math Tasks

Quantitative concepts. The regression results indicated that reactivity significantly predicted performance on the Quantitative Concepts task $\beta = 18.074$, $t(83) = -2.60$, $p = .01$. The effect size for high to low reactivity was moderate; the high reactivity group performed more poorly than the low reactivity group ($d = -.55$). Reactivity explained approximately 6% of the variance in performance on the Quantitative Concepts tasks and 36% of the variance was explained by MD/TA and reactivity ($R^2 = .305$; MD/TA and reactivity $R^2 = .36$).

Spatial rotation. The regression results indicated that reactivity did not significantly predict performance on the Block Rotation task, $\beta = -3.156$, $t(83) = -.300$, ns. The effect size was negligible ($d = -.08$), and reactivity explained only .001% of the variance in performance on the Block Rotation task and approximately 4% of the variance was explained by MD/TA and reactivity ($R^2 = .035$; MD/TA and reactivity $R^2 = .036$).

The results indicated that reactivity predicted performance on the Working Memory for Numbers, Working Memory for Words and Quantitative Concepts tasks. As reactivity increased, performance significantly decreased on these tasks. The effect sizes for reactivity ranged from moderate to large (.57 to .81) indicating that children in the high reactivity group obtained significantly lower scores on these tasks compared to the children in the low reactivity group.
How Do Children with MD Differ from their TA Peers in Cortisol Levels, in Reactivity and in Circadian Rhythm?

To answer this question cortisol levels were measured at four separate time points: T1, T2, T3, and T4. T1 was collected at the start of testing and was used as an indicator of basal or undisturbed cortisol levels. T1 was used as a baseline for comparison with T2, which was collected 30 minutes after the start of testing as a marker of the change in cortisol levels during testing. T3 was collected at 9 A.M. on Day 2 (a day where no testing occurred or was anticipated) as an indicator of morning circulating cortisol levels. T4 was collected at 2:45 P.M. on Day 2 as an indicator of cortisol levels in the afternoon on a day when no testing occurred. A comparison of T3 and T4 indicated the change in cortisol levels from morning to afternoon. To assess the differences in cortisol levels at T1, T2, T3, and T4 by MD and TA a series of independent t-tests were conducted and alpha was set at p < .05 for H0: μ1 = μ2.

Absolute cortisol levels at T1, T2, T3, and T4 by MD and TA. The descriptive statistics for absolute cortisol levels at times T1, T2, T3, and T4 by MD and TA and for the change in absolute cortisol at each of the reactivity times-T1 to T2, T2 to T4 and T3 to T4 are presented in Table 3.5. The absolute cortisol means for the children with MD were higher at each time compared to the TA children for T1, T2, T3, and T4, for reactivity and circadian rhythm.

Log transformed cortisol levels at T1, T2, T3, and T4. Cortisol values were log transformed for the analyses to adjust for positive skew and to reduce the leverage or influence of higher and lower absolute values on performance. The descriptive statistics for log transformed cortisol levels at T1, T2, T3, and T4 are presented in Table 3.6.
Table 3.5

Descriptive Statistics for Absolute Cortisol Levels (ug/dL) at T1, T2, T3, and T4, Cortisol Reactivity and Circadian Rhythm

<table>
<thead>
<tr>
<th>Cortisol levels</th>
<th>MD (n = 39)</th>
<th>TA (n = 44)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>T1</td>
<td>.048</td>
<td>.478</td>
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<tr>
<td>T2</td>
<td>.058</td>
<td>.460</td>
</tr>
<tr>
<td>T3</td>
<td>.070</td>
<td>1.519</td>
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<tr>
<td>T4</td>
<td>.037</td>
<td>1.328</td>
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<tr>
<td>T1-T2 cortisol change</td>
<td>-.151</td>
<td>.218</td>
</tr>
<tr>
<td>T2-T4 cortisol change</td>
<td>-.295</td>
<td>1.173</td>
</tr>
<tr>
<td>T3- T4 cortisol change</td>
<td>-1.21</td>
<td>.063</td>
</tr>
</tbody>
</table>

Note. Negative values for ug/dL (micrograms per decilitre) reflect a decrease in cortisol levels.

Table 3.6

Cortisol at T1, T2, T3, and T4, Cortisol Reactivity and Circadian Rhythm (Log Transformed)

<table>
<thead>
<tr>
<th>Cortisol levels</th>
<th>MD (n = 39)</th>
<th>TA (n = 44)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>T1</td>
<td>-1.31</td>
<td>-.320</td>
</tr>
<tr>
<td>T2</td>
<td>-1.23</td>
<td>-.337</td>
</tr>
<tr>
<td>T3</td>
<td>-1.15</td>
<td>.181</td>
</tr>
<tr>
<td>T4</td>
<td>-1.43</td>
<td>.123</td>
</tr>
<tr>
<td>T1-T2 cortisol increase</td>
<td>-.405</td>
<td>.593</td>
</tr>
<tr>
<td>T2-T4 cortisol increase</td>
<td>-.90</td>
<td>.93</td>
</tr>
<tr>
<td>T3- T4 cortisol increase</td>
<td>-1.23</td>
<td>.18</td>
</tr>
</tbody>
</table>
Calculation of reactivity. Reactivity was computed on log transformed data by subtracting the values at T1 from values at T2 (T2-T1). To assess differences in reactivity between the children with MD and their TA peers at T1 to T2, independent t-tests were conducted.

Computation of difference in reactivity at T2 to T4. Similarly, cortisol reactivity was computed by subtracting the values at T2 from the values at T4 level (T4 − T2 = increase). A difference score between cortisol levels at time T2 (during testing) and time T4 (Day 2 afternoon) was calculated for each participant to determine whether testing itself resulted in a rise in cortisol levels compared to normal afternoon levels. To assess differences in reactivity between the children with MD and their TA peers at T2 to T4, independent t-tests were conducted.

Computation of circadian rhythm. In addition, the cortisol change from T3 compared to T4 was computed on data by subtracting the T3 levels from the T4 levels (T4 − T3 = decrease from AM to PM). To assess differences in circadian rhythm between the children with MD and TA independent t-tests were conducted.

Descriptive statistics for log transformed cortisol levels at T1, T2, T3, and T4, by MD and TA. The descriptive statistics for log transformed cortisol levels at times T1, T2, T3, and T4 by MD and TA and for the change in cortisol at each of the reactivity times: T1 to T2, T2 to T4 and T3 to T4 are presented in Table 3.6.

Do Children with MD have Higher Cortisol Levels at T1, T2, T3, or T4 Compared to their TA Peers?

Cortisol levels at T1, T2, T3, and T4 by MD and TA. The independent t-test results indicated that the difference between children with MD and TA was not statistically significant
at any time \( T_1, t(81) = .653, \) ns; \( T_2, t(81) = 1.118, \) ns; \( T_3, t(81) = .220, \) ns; \( T_4, t(81) = .748, \) ns. These findings indicate that grade 1 children with MD do not differ from their TA peers in terms of their cortisol levels at \( T_1, T_2, T_3, \) or \( T_4. \)

Do Children with MD have Higher Reactivity at \( T_1 \) to \( T_2, T_2 \) to \( T_4, \) or an altered Circadian Rhythm Compared to their TA Peers?

Independent t-tests revealed no statistically significant differences in cortisol levels between the children with MD or TA for the \( T_1 \) to \( T_2 \) reactivity period, \( t(81) = .329, \) ns, for the \( T_2 \) to \( T_4 \) reactivity period, \( t(81) = -1.15, \) ns, or for circadian rhythm (\( T_3 \) to \( T_4 \)), \( t(81) = .365, \) ns.

In summary, there were no statistically significant differences in cortisol levels between children with MD or TA at \( T_1, T_2, T_3, \) or \( T_4, \) or in cortisol levels at \( T_1 \) to \( T_2, T_3 \) to \( T_4, \) or circadian rhythm.

Does Reactivity Affect Children with MD and TA Differently in Terms of their Performance On Working Memory, Processing Speed and Math Tasks?

Children with MD did not perform differently than TA children on the nine tasks as a consequence of reactivity. The interaction results for MD/TA and reactivity were not statistically significant for the cognitive tasks.

Descriptive statistics for cognitive tasks by MD, TA, and reactivity. The descriptive statistics for children grouped by MD/TA and reactivity are presented in Table 3.7. The descriptive statistics show that the means for children with MD and high reactivity are lower than the other MD/TA reactivity groupings for three of the working memory tasks: Working Memory for Numbers, Working Memory for Words, and Letter Number Sequence. Children with MD and high reactivity obtained lower mean scores than those with low reactivity on Working Memory for Numbers, Working Memory for Words, Digit Span Forwards, Rapid
Table 3.7

Descriptive Statistics of Performance Measures by MD/TA and Cortisol Reactivity Increase at T2 in Comparison to T1

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Typical Achievers (TA)</th>
<th>Math Disability (MD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low (n = 10)</td>
<td>Moderate (n = 24)</td>
</tr>
<tr>
<td></td>
<td>M  SD</td>
<td>M  SD</td>
</tr>
<tr>
<td>WM for numbers</td>
<td>4.80 1.47</td>
<td>4.00 1.38</td>
</tr>
<tr>
<td>WM for words</td>
<td>2.90 1.10</td>
<td>2.79 1.25</td>
</tr>
<tr>
<td>Digit span forwards</td>
<td>7.40 1.35</td>
<td>7.92 1.47</td>
</tr>
<tr>
<td>Digit span backwards</td>
<td>5.00 1.05</td>
<td>5.17 1.60</td>
</tr>
<tr>
<td>Rapid number naming</td>
<td>15.70 3.71</td>
<td>14.88 4.01</td>
</tr>
<tr>
<td>Rapid picture naming</td>
<td>107.70 11.22</td>
<td>106.00 11.94</td>
</tr>
<tr>
<td>Letter number sequence</td>
<td>9.50 3.20</td>
<td>9.38 2.85</td>
</tr>
<tr>
<td>Quantitative concepts</td>
<td>118.60 9.43</td>
<td>107.79 13.54</td>
</tr>
<tr>
<td>Block rotation</td>
<td>109.00 12.86</td>
<td>106.08 18.61</td>
</tr>
</tbody>
</table>
Picture Naming, Letter Number Sequence, and Quantitative Concepts. TA children with high reactivity exhibited the same pattern, that is, those with high reactivity performed more poorly on Working Memory for Numbers, Working Memory for Words, and Quantitative Concepts than those with low reactivity.

The interaction results for MD/TA and reactivity for the performance tasks are presented below. The effect sizes for TA children compared by high and low reactivity and the effect sizes for children with MD compared by high and low reactivity categories are reported in Table 3.8.

There were no statistically significant interactions for MD/TA and reactivity for the nine cognitive tasks. The negative direction of effect sizes for reactivity was the same for children with MD and for TA children. Children with MD and TA in the high reactivity category performed more poorly than those in the low reactivity category for all tasks except the Letter Number Sequence task. On this task, the TA children with high reactivity performed better than the TA children with low reactivity (d = .21). The effect size for reactivity on the Letter Number Sequence task for children with MD in the high reactivity group was large (d = -1.28); the high reactivity group performed more poorly than the low reactivity group.

How Does Reactivity Affect Performance Within the MD Group?

To investigate this question, independent t-tests were conducted between the high and low reactivity groups for the children with MD on the tasks that were impaired for children with MD, Letter Number Sequence and Quantitative Concepts and on the tasks that were functionally impaired in children with MD. Mean difference effect sizes were
calculated to show the magnitude of effect of high reactivity for the children with MD on the tasks that were impaired in children with MD.

Table 3.8

ANOVA Summary Table for MD/TA and Reactivity Effect Size for the Cognitive Tasks

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>F</th>
<th>p</th>
<th>TA d</th>
<th>MD d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working memory for numbers</td>
<td>2.0</td>
<td>0.15</td>
<td>-.70</td>
<td>-.59</td>
</tr>
<tr>
<td>Working memory for words</td>
<td>2.67</td>
<td>0.10</td>
<td>-1.18</td>
<td>-.58</td>
</tr>
<tr>
<td>Digit span forwards</td>
<td>1.14</td>
<td>0.28</td>
<td>-.20</td>
<td>-.13</td>
</tr>
<tr>
<td>Digit span backwards</td>
<td>.31</td>
<td>0.57</td>
<td>-.28</td>
<td>-.09</td>
</tr>
<tr>
<td>Rapid number naming</td>
<td>.83</td>
<td>0.36</td>
<td>-.22</td>
<td>-.03</td>
</tr>
<tr>
<td>Rapid picture naming</td>
<td>1.28</td>
<td>0.26</td>
<td>.32</td>
<td>-.78</td>
</tr>
<tr>
<td>Letter number sequence</td>
<td>2.69</td>
<td>0.10</td>
<td>.21</td>
<td>-1.28</td>
</tr>
<tr>
<td>Quantitative concepts</td>
<td>.45</td>
<td>0.50</td>
<td>-.83</td>
<td>-.50</td>
</tr>
<tr>
<td>Block rotation</td>
<td>.43</td>
<td>0.51</td>
<td>-.63</td>
<td>-.29</td>
</tr>
</tbody>
</table>

Note: d is the standardized mean difference for the TA high to TA low and for the MD high to MD low. The negative d indicates that children with high reactivity obtained lower scores than children with low reactivity.

*p < .05

MD, reactivity, and working memory for numbers. The results of independent t-tests indicated no statistically significant differences between children with MD and high reactivity compared to those with low reactivity for this task, t (20) = 1.447, ns. The moderate effect size (d = -.59) suggests that functionally children with MD and high reactivity perform more poorly than children with MD and low reactivity on the Working Memory for Numbers task. The sub sample for this comparison for this was small (low n
= 11, high n = 11) and the low power of this analyses may explain the non-significant finding.

MD, reactivity, and working memory for words. Independent t-tests indicated no statistically significant differences in performance for children with MD by low and high reactivity, t (20) = 1.445, ns. The effect size for this comparison was moderate (d = -.58) indicating that functionally children with high reactivity and MD are more impaired on the Working Memory for Words task compared to those with low reactivity.

MD, reactivity, and letter number sequence. Independent t-tests indicated significant differences in performance for children with MD by high and low reactivity, t (20) = 3.141, p = .005. The high reactivity group obtained lower scores than the low reactivity group and the effect size for this comparison was large (d = -1.28).

MD, reactivity and digits forwards. The results for independent t-tests indicated no significant differences in performance between the children with MD and high reactivity and low reactivity on the Digits Forwards task, t (20) = .328, ns and the effect size for this comparison was small (d = -.13).

MD, reactivity, and rapid number naming. The independent t-test for children with MD and high and low reactivity was not significant for the Rapid Number Naming task, t (20) = .074, ns, and the effect size for this comparison was negligible (d = -.03).

MD, reactivity, and quantitative concepts. The independent t-test for children with MD and high reactivity and low reactivity was not significant for the Quantitative Concepts task, t (20) = 1.216, ns. The effect size for this comparison was moderate (d = -.51) with the high reactivity group performing more poorly than the low reactivity group.
These tests did not reach significance due to the small sample and multiple comparisons (high n = 11; low n = 11).

In summary, there were significant differences between the children with MD and high reactivity and low reactivity on the Letter Number Sequence task, a finding that is important because this is a task that is impaired in children with MD. Test results did not meet standards of statistical significance for Working Memory for Numbers, Working Memory for Words, and Quantitative Concepts, although the effect sizes indicated that children with MD and high reactivity perform less efficiently compared to those with MD and lower levels of reactivity.

How Does Sex and Reactivity Affect Performance?

Sex and Reactivity

Sex and performance on the cognitive tasks. ANOVA was used to examine whether there were differences in performance by sex on the nine cognitive tasks. Results of the ANOVAs are presented in Table 3.9.

The results indicated no statistically significant differences between children by sex. Effect sizes for sex and the cognitive tasks were small, indicating no functional differences between girls and boys on the cognitive tasks.

Does Reactivity Affect Boys Differently from Girls on the Working Memory, Processing Speed, and Math Tasks?

Sex and reactivity. The interaction results for sex and reactivity are presented in Table 3.10. Results were not statistically significant for sex and reactivity for any of the tasks. The effect size for girls and boys with high reactivity for Working Memory for
Numbers and Digits Forwards was large; boys with high reactivity performed better than girls with high reactivity.

Table 3.9

ANOVA Summary Table for Sex and the Cognitive Tasks

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>F</th>
<th>p</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working memory for numbers</td>
<td>1.05</td>
<td>0.30</td>
<td>-.22</td>
</tr>
<tr>
<td>Working memory for words</td>
<td>.00</td>
<td>0.98</td>
<td>-.00</td>
</tr>
<tr>
<td>Digit span forwards</td>
<td>3.91</td>
<td>0.05</td>
<td>-.27</td>
</tr>
<tr>
<td>Digit span backwards</td>
<td>.13</td>
<td>0.71</td>
<td>.08</td>
</tr>
<tr>
<td>Rapid number naming</td>
<td>1.94</td>
<td>0.16</td>
<td>-.30</td>
</tr>
<tr>
<td>Rapid picture naming</td>
<td>3.64</td>
<td>0.06</td>
<td>.33</td>
</tr>
<tr>
<td>Letter number sequence</td>
<td>2.56</td>
<td>0.11</td>
<td>-.35</td>
</tr>
<tr>
<td>Quantitative concepts</td>
<td>2.35</td>
<td>0.12</td>
<td>-.41</td>
</tr>
<tr>
<td>Block rotation</td>
<td>.00</td>
<td>0.96</td>
<td>.01</td>
</tr>
</tbody>
</table>

The d calculation for girls versus boys. A negative effect size indicates that boys performed better than girls.

In summary, children did not exhibit significant differences on the cognitive tasks by sex. There were no significant interactions for sex and reactivity. The large effect size for sex and high reactivity on the Working Memory for Numbers (d = -1.02) and Digit Span Forwards (d = -1.26) indicated that functionally boys with high reactivity performed better than girls with high reactivity on these tasks. The sample was small for gender and reactivity (girls high n = 10; girls low n= 11; boys high n = 11; boys low = n=10) but effect sizes may be indicative of a trend that is worthy of further investigation. These findings should be interpreted with caution as results were not statistically significant.
Table 3.10

ANOVA Summary Table for Sex and Reactivity Effect Size for the Cognitive Tasks.

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>F</th>
<th>p</th>
<th>Sex High d</th>
<th>Sex Low d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working memory for numbers</td>
<td>1.93</td>
<td>0.16</td>
<td>-1.02</td>
<td>-0.18</td>
</tr>
<tr>
<td>Working memory for words</td>
<td>.40</td>
<td>0.52</td>
<td>-0.04</td>
<td>-0.25</td>
</tr>
<tr>
<td>Digit span forwards</td>
<td>3.98</td>
<td>0.04</td>
<td>-1.26</td>
<td>-0.08</td>
</tr>
<tr>
<td>Digit span backwards</td>
<td>.10</td>
<td>0.74</td>
<td>0.04</td>
<td>0.09</td>
</tr>
<tr>
<td>Rapid number naming</td>
<td>0.04</td>
<td>0.83</td>
<td>0.19</td>
<td>0.47</td>
</tr>
<tr>
<td>Rapid picture naming</td>
<td>.04</td>
<td>0.83</td>
<td>0.44</td>
<td>0.48</td>
</tr>
<tr>
<td>Letter number sequence</td>
<td>.15</td>
<td>0.69</td>
<td>-0.57</td>
<td>-0.35</td>
</tr>
<tr>
<td>Quantitative concepts</td>
<td>.00</td>
<td>0.98</td>
<td>-0.50</td>
<td>-0.44</td>
</tr>
<tr>
<td>Block rotation</td>
<td>1.64</td>
<td>0.20</td>
<td>0.29</td>
<td>-0.41</td>
</tr>
</tbody>
</table>

Note: d calculated for sex and high reactivity and sex and low reactivity. Negative d indicates that boys performed better than girls.
CHAPTER IV: DISCUSSION AND CONCLUSIONS

Major Findings

The first major finding of this study was that grade 1 children with MD exhibited a working memory deficit compared to their TA peers on the Letter Number Sequence task. Children with MD did not exhibit differences their short-term storage capacity for numbers (phonological loop), or in their processing speed for numbers or words, in comparison to their TA peers. Several caveats are discussed in the section that follows to provide some possible explanations for the differences in findings in this study from the existing literature. No statistical differences were found between grade 1 children with MD compared to their TA peers on the spatial rotation task.

The second major finding of this study indicated that for both groups of children, reactivity to stress influenced performance on working memory tasks for numerical and verbal information, and performance on math tasks; children with high reactivity performed more poorly than those with low reactivity.

The third major finding of this study was that children with MD exhibited no significant differences from their TA peers in cortisol levels at the four measurement points, in terms of reactivity or circadian rhythm.

The fourth major finding was that there were no significant differences in performance in children grouped by MD/TA and reactivity; overall high reactivity affected children with MD and TA similarly; those with high reactivity had poorer performance than those with low reactivity. Children with MD and high reactivity performed significantly more poorly than those with low reactivity on the Letter Number Sequence task, a task that this study found impaired in grade 1 children with MD.
The last major finding was that there were no differences in performance between children by sex, and there were no significant differences between boys and girls with high reactivity or low reactivity.

The Role of MD in the Performance of Cognitive Tasks

Working Memory

The first question in this study investigated whether grade 1 children with MD differed in terms of their performance on working memory, processing speed and math tasks. With regards to working memory, I addressed the question of whether the impairments were a domain general working memory impairment for numerical, verbal and alphabetic information or a domain specific impairment for numerical information only.

Grade 1 children with MD exhibited a working memory deficit compared to their TA peers on the Letter Number Sequence task, but tests did not reach statistical significance for working memory for numbers, working memory for words, or digits backwards. The statistical findings suggest that children with MD do not have a domain general working memory impairment compared to their TA peers. The impairment suggested by the effect sizes (above -.40 for both working memory for numbers and words) suggests that functionally, grade 1 children with MD did perform more poorly on working memory tasks for numbers and words compared to their TA peers. The statistical evidence in this study offers some support for a working memory impairment on tasks involving letters and numbers, a finding that corroborates research that has found children with MD are impaired in working memory for numbers or on counting type working memory tasks (Hitch & McAuley, 1991; Siegel & Ryan, 1987). Several factors
suggest that a general working memory deficit cannot be entirely ruled out by the non
significant results for working memory for numbers and words and these factors need to
be considered. First, it is difficult to identify a “purely” MD sample in grade 1 children
because children perform more poorly on math screening measures for a variety of
reasons, but may not have MD. Geary et al., (1999) followed a group of children and
found that low achievement in grade 1 did not consistently identify children with MD in
later grades. Therefore some of the children in this MD sample may have been false
positives and this could have inflated scores on the tasks that are believed to be impaired
in children with MD. Findings may not have met statistical significance due to the
presence of false positives when true differences between groups of MD and TA may
exist. Finally, the sample included three types of MD, those with problems in
calculation, those with problems in applied math and those with problems in both. Each
of these subtypes of MD may have differing underlying cognitive processes that are
impaired. These factors taken together converge to suggest that a general working
memory deficit cannot be ruled out by the findings of this study. Children with MD do
differ from their TA peers on a number of working memory tasks, but results were only
significant for the Letter Number Sequence task. The findings of this study are not
statistically consistent with the literature that posits that a general working memory
impairment is involved in MD, although interpreted with the aforementioned caveats
suggest a trend in this direction (Geary et al., 2007; Passolunghi & Siegel, 2001, 2004;
Swanson & Jerman, 2006; Swanson & Sachse-Lee, 2001).

Phonological Loop

The second part of the first question addressed which of the components of
working memory were impaired in children with MD. This study provides statistical
evidence that the phonological loop or short-term storage for small amounts of speech
based information, such as recalling numbers, is not impaired in children with MD.

This particular component of working memory has been investigated in numerous
studies because of its possible implication in the less efficient working memory
performance of children with MD. The hypothesis is that children with MD would have
weaker working memory and fail to develop basic number fact representations in long-
term memory because of the rapid decay of information in short term storage. The
second major finding of this study confirmed that children with MD and TA do not differ
in terms of their capacity on the Digit Span Forward task. These findings are consistent
with studies that have controlled for reading ability and have not found an impairment on
tasks that involve the phonological loop (Bull & Johnson, 1997; McLean & Hitch, 1999;
Passolunghi & Siegel, 2004). Numerous studies that did find a reduced short-term storage
capacity in children with MD (Geary et al., 2000; Geary et al., 1991; Geary et al., 1999;
Hitch & McAuley, 1991; Passolunghi & Siegel, 2001; Siegel & Ryan 1989), included
older children with math problem solving in their sample, and some of the studies did
not control for RD. The inclusion of several subtypes of MD, those with calculation
problems and/or those with applied math problems and the possibility of false positives in
the MD sample may account for some of the differences in findings between studies.

Processing Speed

The first question in this study also addressed whether processing speed for
numbers or words is deficient in children with MD. This study did not find statistical
evidence of impairment in process speed for numbers, but grade 1 children with MD were slower to process numerical information their TA peers \( (d = -.55) \).

Some of the literature supports an impairment in processing speed for numbers (Bull & Johnson, 1997; Geary et al., 2007; Hitch & McAuley, 1991; Swanson & Jerman, 2006) and suggests that children with MD are slower retrieving and/or accessing numerical representations in long term memory compared to their TA peers. Passolunghi and Siegel (2004) did not find this impairment in processing speed in grade 5 children with MD. It has been proposed in the literature (Case, 1985; Kail, 1992; Kail & Hall, 1999) that slow processing speed or retrieval of information from long term memory affects the amount of information that can be held in short-term storage and contributes to the impairment in working memory found in children with MD.

The lack of significance for processing speed for numbers may reflect the presence of false positives in the MD sample and the inclusion of two types of math disability.

Spatial Rotation

There have not been consistent findings with regard to whether visual spatial rotation is impaired in children with MD. Visual spatial rotation has been confounded with motor skills in many of the studies, therefore it is difficult to generalize as to whether children with MD exhibit an impairment in spatial rotation. This study found no significant differences between children with MD and TA children on Block Rotation, a task requiring the manipulation of spatial information without a motor component.
Quantitative Concepts

Children with MD obtained significantly lower scores on Quantitative Concepts compared to their TA peers. These results indicate that grade 1 children with MD have significantly more difficulty with tasks involving cardinal ordering, counting, sequencing, and number series compared to their TA peers. These findings are consistent with a number of studies that have found that young children with MD make more errors on counting tasks than their TA peers (Geary, Hamson & Hoard, 2000; Geary Hoard & Hamson, 1999; Jordan & Montani, 1997).

Reactivity to Stress

The second research question addressed whether and how reactivity to stress affected performance on the cognitive tasks believed to underlie MD. The finding that reactivity to stress predicted performance on math tasks and working memory tasks for numerical and verbal information, is important for educators as it provides evidence that grade 1 children’s response to stress influences performance on working memory tasks and math tasks. We found that for both groups of grade 1 children, higher reactivity was associated with poorer performance than those children with lower levels of reactivity. This finding is important because high reactivity may be interfering with working memory and math performance and may prevent children from reaching their full potential as learners particularly on tasks involving working memory, such as math computation and carrying procedures. Working memory for numbers and words are cognitive tasks that are functionally impaired in children with MD, and the results indicated that children with MD and high reactivity exhibited the poorest performance overall on the working memory tasks that are impaired in children with MD.
Differences in Cortisol Levels, Reactivity and Circadian Rhythm

The third question addressed whether children with MD differ significantly from their TA peers in cortisol levels at T1, T2, T3, or T4, in reactivity, or whether they have an altered circadian rhythm compared to their TA peers. A major finding of this study was that children with MD exhibited no statistically significant differences from their TA peers in cortisol levels at the four times, in reactivity, or in circadian rhythm.

MD/TA, Reactivity and Performance

The fourth research question addressed how children grouped by MD/TA and reactivity to stress performed on the tasks that are impaired in children with MD. There were no significant differences in performance in the children grouped by MD/TA and reactivity.

The finding that children with MD and high reactivity performed statistically more poorly on the Letter Number Sequence task than children with MD and low reactivity and that, functionally, children with MD and high reactivity exhibited a trend towards more impairment on Working Memory for Numbers, Working Memory for Words, Digits Forwards, Rapid Number Naming, and Quantitative Concepts compared to children with MD and lower levels of reactivity suggests that the response to stress is an important variable for educators to consider in children’s learning.

Sex and Reactivity

The last question examined whether boys and girls performed differently on the cognitive tasks and whether reactivity was implicated in these differences. There were no differences by sex for any of the tasks and there were no significant interactions for sex and reactivity on the performance tasks. A large effect size was observed for Working
Memory for Numbers and the Digits Forwards task suggesting a trend that may be worthy of further investigation; functionally boys with high reactivity performed better than girls with high reactivity on these tasks. Previous studies with adults have found that males exhibited a higher cortisol response to stress than females (Sauro et al., 2003).

Implications for Contributions to Theory and Research

To date, the research investigating the processes involved in MD has focused on (a) identifying the key cognitive components of MD, (b) a general working memory deficit or a specific deficit in working memory for numbers, and (c) investigating which of the specific components of working memory (phonological loop, central executive, visual spatial sketchpad or processing speed) contribute most to the deficits in working memory that are evident amongst children with MD. The literature posits several explanations for the impairments in working memory found in children with MD. First, a reduced short storage capacity (phonological loop) has been implicated in an impaired working memory. Slow process speed or the ability to retrieve information from long term memory has been linked to impaired working memory resources due to the slow rehearsal time (Bull & Johnson, 1997; Kail, 1992). The second explanation is that an impairment in working memory is due to the central executive caused by poor selective attention to verbal information (Swanson & Jerman, 2006) and/or an impairment in the inhibitory mechanism that affects the retrieval process resulting in retrieval errors (Barrouillet et al., 1997; Geary et al., 2000; Passolunghi & Siegel, 2001, 2004).

The first explanation for the working memory impairment is that slow processing or difficulty accessing numerical representations from long-term memory is linked to working memory capacity and the smaller short term storage capacity of children with
MD (Kail & Hall, 1994). This study found that children with MD had functionally lower scores on the short-term storage task for numbers and rate of number naming, which supports the process speed explanation for difficulties in executing working memory tasks. However, results did not meet statistical significance for the processing speed for numbers or words, or for working memory for numbers or words in this sample of children. The functionally lower scores on working memory tasks for numbers and words, interpreted and considered with the mentioned methodological caveats, the significantly lower performance on the Letter Number Sequence task in children with MD, and the relatively consistent findings in the literature that have found a general working memory impairment in children with MD, suggests that the difficulties experienced by children with MD could be linked to tasks requiring the central executive.

The finding that higher levels of reactivity significantly predicted lower performance on two of the working memory tasks and the math tasks is theoretically consistent with the hypothesis that the central executive is impaired by interference during the retrieval process (Barrouillet et al., 1997; Passolunghi & Siegel, 2001, 2004). The finding that high reactivity significantly affects performance on working memory tasks in both groups of children is theoretically and empirically consistent with the literature that has found that the arousal of math anxiety prior to math performance is associated with poor math performance (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007; Hembree, 1990; Seyler et al., 2003). These studies found that individuals with the self-reported experience of high math anxiety performed more poorly on math tasks that require working memory and on working memory tasks. These researchers contend that working memory is only compromised when math anxiety is aroused and that when
support is provided the working memory deficits improve (Hembree, 1990). Ashcraft & Krause (2007) argued that it is the experience of anxiety that causes a disruption in working memory that contributes to the poor execution of math computation and working memory in individuals with math anxiety. My study provides physiological evidence for this relationship. A major finding of this study was that higher levels of reactivity predicted poorer performance on working memory and quantitative concepts tasks in both groups of children.

The reactivity findings are also theoretically and empirically consistent with the literature that has investigated stress and the declarative memory system in children. In particular, high reactivity impaired verbal retrieval in young children and when provided with support, recall improved (Quas & Lench, 2007). Blair et al. (2005) found that an increase in cortisol levels prior to testing followed by a decrease in cortisol levels during testing was associated with better performance on measures of executive function self-regulation and letter knowledge in children age 4 and 5. In this study, the children with higher reactivity, that is the children with larger increases in cortisol levels during testing, had lower scores than the children with lower reactivity during testing on working memory for numbers and words. These findings are also consistent with the literature that has investigated stress and memory in adults and support this study’s hypothesis that high reactivity disrupts working memory in grade 1 children. For grade 1 children with MD and high reactivity, working memory performance was the poorest on the Letter Number Sequence task. These findings lend some support to engaging children in instructional and learning strategies that are supportive.
Math Disability, Working Memory, and Reactivity to Stress

The findings of this study provide evidence that both groups of children (those with MD and TA) with high reactivity exhibited a statistically significant general working memory deficit for numerical and verbal information compared to children with lower levels of reactivity. These findings are important because working memory is a core component of mathematical competency and a reduced capacity due to the stress response may limit children from their learning potential. For children with MD, these findings are particularly important because they perform significantly more poorly than TA children on working memory tasks generally. Performance on working memory tasks is already impaired and it appears high reactivity compounds these difficulties. Children with MD and high reactivity obtained the lowest scores of any of the groupings on Letter Number Sequence, a task that is impaired in children with MD.

Another finding of this study was the moderate effect sizes for children with MD and high reactivity compared to those with MD and low reactivity on the Working Memory for Numbers and Working Memory for Words tasks, processes that have been shown to be impaired in children with MD. While these tests did not meet conventional standards of statistical significance, perhaps due to the multiple comparisons and small sample size, the moderate effect sizes indicate functional impairments for children with MD in comparison to children with MD and lower levels of reactivity. There was also a moderate effect size found for children with MD and high reactivity compared to children with low reactivity on Rapid Picture Naming task.
Implications for Contributions to Practice

Early Screening Measures for Reactivity

The findings of this study suggest that identifying children with high reactivity to stress is an important variable to consider when identifying children who may be at risk for developing working memory impairments that underlie MD. The relationship between reactivity and performance on Working Memory for Numbers, Working Memory for Words, and math tasks indicates that high reactivity may exacerbate the difficulties experienced by children with MD and contribute to their poor performance in math.

Reactivity to stress. Although research into the construct of reactivity is relatively new to education, the findings of this study suggest that attention to self-reports of stress in children to identify children with high reactivity to stress may be helpful in identifying children who might benefit from methods to reduce reactivity and improve their ability to learn. Clinical interviews and the use of parent rating scales may be helpful in identifying children who experience high reactivity to stress, since self-report questionnaires have proven problematic with young children.

Index markers of reactivity. School psychologists may consider adding a physiological index of stress by adding saliva samples before and 30 minutes after the start of cognitive abilities testing. The triangulation of self-reports, physiological measures and cognitive abilities testing could accurately identify children who have high reactivity to stress and who are having difficulty with the execution of working memory tasks which then contributes to difficulties in mathematics computation, the execution of counting-based procedures and learning in mathematics. Children identified as highly
reactive, with weak working memory performance and MD may benefit from strategies that reduce reactivity which may improve their ability to learn.

Interventions

It is important to continue to research strategies to improve the working memory capacity of children because this appears to be a key area of impairment for children with high reactivity as well as for children with MD. Mathematical competency is important for participation in a rapidly advancing technological society and math is used as a screening course for upper level science degrees such as engineering and medicine. As early as grade 1, children exhibit difficulties in math and perform poorly on working memory tasks. These difficulties may result from or lead to reactivity. More research is needed to determine whether reducing reactivity improves working memory and performance on math tasks. Some research has shown that when strategies to reduce math anxiety are provided, performance in math improves, and research investigating physiological reactivity and verbal recall tasks in children has demonstrated that with support verbal recall improves (Quas & Lench, 2007).

High reactivity and performance on working memory tasks. A major finding of this study was that high reactivity and poor performance on working memory tasks are linked. Evidence based practical interventions should focus on this finding to help all children with high reactivity reach their learning potential. Working memory is a process that is essential to the development of mathematical competency and the findings suggest that high reactivity interferes with working memory performance. Children with high reactivity may benefit from methods of instruction that reduce reactivity which may improve their ability to learn.
This study also found that children with high reactivity and MD exhibited the most severe impairment of all the children with MD on a measure of working memory that is impaired in children with MD. More research is needed to confirm these findings, and until then these results should be interpreted with caution, but findings suggest that children with MD and high reactivity to stress maybe a subset of children with MD who will benefit from strategies and alternate methods of instruction to reduce their reactivity and this may improve the ability to learn in math.

Limitations and Future Directions

Multiple Dependent Variables

This study used multiple dependent variables to investigate the cognitive components of MD and their relationship to reactivity. The numerous comparisons and small sample size (n) reduced the overall power of these tests. To solve this problem future research should use larger samples and might target a smaller number a smaller number of targeted working memory variables and specific math tasks as measures.

MD Selection Criteria

There were two types of math disability included in this study, those with a disability in math calculation and those with a disability in applied problems and those with problems in both. The inclusion of two types of math disability may confound the findings. Geary et al. (1999) followed a group of grade 1 children with math difficulties longitudinally and found that low achievement in grade 1 did not consistently identify children with MD. This finding needs to be taken into consideration as some of the children identified may not have math disability and this may explain some of the inconsistencies in research findings with children with MD in higher grades.
Cortisol Testing

The testing of young children is less reliable than with older children, but no more than what is normally encountered in testing grade 1 children in a psycho-educational assessment. External validity concerns were also extended to how cortisol test results can be influenced by food eaten and level of physical activity. This factor was taken into consideration in the research design and all the children ate lunch at noon and had their usual play time prior to testing. Activities at home prior to the day 2 of testing could influence cortisol levels.

The inclusion of a Likert scale self-report of anxiety was considered at the outset of this study. It was not included due to the lack of validity of such measures at this age. In older students, the inclusion of a self-report of anxiety is recommended in future studies of reactivity to triangulate findings.

Emotional regulation and contextual support. More research is needed to determine whether reducing reactivity improves performance on working memory or math tasks. Working memory is required for beginning math computation and continues to be important for higher levels of math computation (Ashcraft & Krause, 2007). Working memory tasks are included in psycho-educational assessments and the working memory scores are typically included in a battery of scores that generate the overall general cognitive ability score (i.e., the Working Memory Index of the WISC-IV). High reactivity may interfere with performance on the working memory tasks included in cognitive assessments and can affect overall scores in two ways. First, lower working memory scores contribute to a lower Working Memory Index score, which when included in estimating overall IQ, lowers the IQ score. Second, lower working memory
scores may identify the student as having a process deficit in the area of working memory, when the student may have a high response to stress which is interfering with their ability to perform working memory tasks. Research is needed to investigate how reactivity to stress might influence performance and deflate overall IQ scores.

Research into emotional regulation, meta-cognitive strategies and human support such as the availability of small group instruction and supportive instruction is recommended to investigate how these might reduce children’s reactivity to stress and improve their ability to learn. There has been some research into the construct of emotional regulation (Eisenberg et al., 2004), into regulation of reactivity (Rothbart & Derryberry, 1981; Rothbart, Posner, & Kieras, 2006), and meta-cognitive/self-regulation strategies (Winne & Perry, 2000). There has been research that has found that contextual support for individuals with high reactivity improves their performance on verbal memory tasks (Quas & Lench, 2007). Research has shown that cognitive behavioural strategies to reduce math anxiety has resulted in significantly improved math performance (d = .57) (Hembree, 1990).

There has been no research into emotional regulation or regulation of reactivity and the relationship to cognitive function in young children. The finding that children with higher reactivity performed more poorly on working memory tasks indicates that this is an important area of continued research. Future research to investigate practical instructional methods to reduce reactivity may improve children’s performance on working memory tasks and their learning in general. Longitudinal studies that include physiological measures of stress and performance on one or two measures of working memory tasks are recommended to confirm these findings in different age groups.
REFERENCES


APPENDIX A

Working Memory Task

Instructions:

I am going to say some sentences and the last word in each sentence will be missing. I want you to tell me what you think the last word should be. Let's try one. "For breakfast the little girl had orange ____________." Now I am going to read two sentences. After each sentence, I want you to tell me the word that should go at the end of the sentence. When I finish the two sentences, I want you to tell me the two words that you said for the end of each sentence. Please tell me the words in the order that you said them. Let's try it. "When we go swimming, we wear a bathing ____________." Cars have to stop at a red ____________.

Discontinue when the child has failed an entire level (i.e. all three items – A, B, C of a particular number)

Note: Announce each new level. Record the words in the order the child has said them.

<table>
<thead>
<tr>
<th>Items</th>
<th>ANY</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>FLAG</td>
</tr>
<tr>
<td>2A</td>
<td></td>
</tr>
<tr>
<td>1) In a baseball game, the pitcher throws the __________________________.</td>
<td></td>
</tr>
<tr>
<td>Child's responses: __________________________ (ball, fingers)</td>
<td></td>
</tr>
<tr>
<td>2) On my two hands, I have ten __________________________.</td>
<td></td>
</tr>
<tr>
<td>Child's responses: __________________________ (fingers)</td>
<td></td>
</tr>
<tr>
<td>2B</td>
<td></td>
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<tr>
<td>1) In the fall, we need to rake __________________________.</td>
<td></td>
</tr>
<tr>
<td>Child's responses: __________________________ (leaves)</td>
<td></td>
</tr>
<tr>
<td>2) When we are sick, we often go to the __________________________.</td>
<td></td>
</tr>
<tr>
<td>Child's responses: __________________________ (doctor)</td>
<td></td>
</tr>
<tr>
<td>2C</td>
<td></td>
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<tr>
<td>1) An elephant is big, a mouse is __________________________.</td>
<td></td>
</tr>
<tr>
<td>Child's responses: __________________________ (small)</td>
<td></td>
</tr>
<tr>
<td>2) A saw is used to cut __________________________.</td>
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<tr>
<td>Child's responses: __________________________ (wood)</td>
<td></td>
</tr>
<tr>
<td>3A</td>
<td></td>
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<tr>
<td>1) Running is fast, walking is __________________________.</td>
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</tr>
<tr>
<td>Child's responses: __________________________ (slow)</td>
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<tr>
<td>2) At the library people read __________________________.</td>
<td></td>
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<tr>
<td>Child's responses: __________________________ (books)</td>
<td></td>
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<tr>
<td>3) An apple is red, a banana is __________________________.</td>
<td></td>
</tr>
<tr>
<td>Child's responses: __________________________ (yellow)</td>
<td></td>
</tr>
<tr>
<td>3B</td>
<td></td>
</tr>
<tr>
<td>1) The sun shines during the day, the moon at __________________________.</td>
<td></td>
</tr>
<tr>
<td>Child's responses: __________________________ (night)</td>
<td></td>
</tr>
<tr>
<td>2) In the spring, the farmer plows the __________________________.</td>
<td></td>
</tr>
<tr>
<td>Child's responses: __________________________ (field)</td>
<td></td>
</tr>
<tr>
<td>3) The young child had black hair and brown __________________________.</td>
<td></td>
</tr>
<tr>
<td>Child's responses: __________________________ (eyes)</td>
<td></td>
</tr>
</tbody>
</table>
3C 1) In the summer it is very _______________________________________________________________________.
   2) People go to see monkeys in a _______________________________________________________________________.
   3) With dinner, we sometimes drink _______________________________________________________________________.
      Child's responses: _____________________________________________________________ (hot, zoo, milk)

4A 1) Please pass the salt and _______________________________________________________________________.
   2) When our hands are cold we wear _______________________________________________________________________.
   3) On the way to school I mailed a _______________________________________________________________________.
   4) After swimming, I was soaking _______________________________________________________________.
      Child's responses: _______________________________________________________________ (pepper, gloves, letter, wet)

4B 1) Snow is white, grass is _______________________________________________________________________.
   2) After school, the children walked _______________________________________________________________________.
   3) A bird flies, a fish _______________________________________________________________________.
   4) In the barn, the farmer milked the _______________________________________________________________________.
      Child's responses: _______________________________________________________________ (green, home, swims, cow)

4C 1) In the autumn, the leaves fall off the _______________________________________________________________________.
   2) We eat soup with a _______________________________________________________________________.
   3) I go to the pool to _______________________________________________________________________.
   4) We brush and comb our _______________________________________________________________________.
      Child's responses: _______________________________________________________________ (trees, spoon, swim, hair)

5A 1) For the party, the girl wore a pretty pink _______________________________________________________________________.
   2) Cotton is soft, and rocks are _______________________________________________________________________.
   3) Once a week, we wash the _______________________________________________________________________.
   4) In the spring it is very _______________________________________________________________________.
   5) I throw the ball up and then it comes _______________________________________________________________.
      Child's responses: _______________________________________________________________ (dress, hard, car..., rainy, down)

5B 1) The snail is slow, the rabbit is _______________________________________________________________________.
   2) At a birthday party, we usually eat ice cream and _______________________________________________________________________.
   3) Sandpaper is rough but glass is _______________________________________________________________________.
   4) In a garden, we pick _______________________________________________________________________.
   5) Over the field, the girl rode the galloping _______________________________________________________________________.
      Child's response: _______________________________________________________________ (fast, cake, smooth, flowers, horse)

5C 1) To cut meat we use a sharp _______________________________________________________________________.
   2) In the daytime it is light, and at night it is _______________________________________________________________________.
   3) Dogs have four _______________________________________________________________________.
   4) At the grocery store, we buy _______________________________________________________________________.
   5) A man is big, a baby is _______________________________________________________________________.
      Child's responses: _______________________________________________________________ (knife, dark, legs, food, small)

NUMBER CORRECT IN ANY ORDER __%/12

NUMBER CORRECT IN EXACT ORDER __%/12
Certificate of Approval

<table>
<thead>
<tr>
<th>PRINCIPAL INVESTIGATOR</th>
<th>DEPARTMENT</th>
<th>NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siegel, L.</td>
<td>Educ Psych/Spec Educ</td>
<td>B06-0295</td>
</tr>
</tbody>
</table>

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT
North Vancouver School District, UBC Campus,

CO-INVESTIGATORS:
Ford, Laurie, Educ & Couns Psych & Spec Educ; Mackinnon-Mcquarrie, Maureen, Educ & Couns Psych & Spec Educ

SPONSORING AGENCIES
Social Sciences & Humanities Research Council

TITLE
Cortisol, Memory, and Math Disabilities

APPROVAL DATE: JUN 14 2006
TERM (YRS): 1
DOCUMENTS INCLUDED IN THIS APPROVAL:
June 12, 2006, Parent Consent Form; May 17, 2006, Assent Form

The application for ethical review of the above-named project has been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approved on behalf of the Behavioural Research Ethics board
by one of the following:
Dr. Peter Suedfeld, Chair,
Dr. Susan Rowley, Associate Chair
Dr. Jim Rupert, Associate Chair
Dr. Arminee Kazanjian, Associate Chair

This Certificate of Approval is valid for the above term provided there is no change in the experimental procedures.
Dear Parent/Guardian,

Please read this form carefully. Please sign one copy and return it to the school. You may keep the other for your records.

This is a request for your child to take part in the SPIT and MEMORY project at your child’s school. It is part of a doctoral dissertation study for Maureen MacKinnon-McQuarrie. Your child is participating in the Math project already. We would like a sample of your child’s saliva before and after the math and memory tasks that your child is taking part in and the next day in the morning and at the end of the day. We would also like access to your child’s confidential test scores from the Math project to use in our research.

Purpose:
The purpose of this study is to see how much cortisol is in your child’s saliva when they are trying to remember things they have learned in school. Cortisol is in everyone, but we make more when we are physically active, nervous or feeling stress. The amount of cortisol has been proven to affect how well we store and retrieve memory. By measuring how much cortisol is in a child’s saliva when they are remembering, we can see how high or low cortisol levels affect children’s memory. This may help us understand why some children remember better than others, and may help us to develop learning environments that reflect the importance of the comfort level of children when learning. If you agree to have your child take part in the study, your child will be asked to chew on a cotton ball about the size of a piece of gum for about 1 minute. This will happen 5 times during the study. Your child will be asked to do things like add and subtract, read some words and repeat numbers from memory. The next day your child will be asked for a sample of their saliva (spit) in the morning and in the afternoon. Your giving permission for your child to take part in this study will help us understand why some students have trouble learning in school and will help us to develop environments where children can learn more easily.

1. If you agree to have your child take part in the study, your child will be asked to chew on a cotton ball about the size of a piece of gum for about 1 minute. This will happen 5
times during the math study. Your child will be asked to do things like add and subtract, read some words and repeat numbers from memory. The next day your child will be asked for a sample of their saliva (spit) in the morning and in the afternoon.

2. The saliva testing and answering questions will take about 15 more minutes of your child’s time in addition to the study they are already involved in.

3. Your child’s name will not be written on any of the tests answer sheets or on the containers with the saliva.

4. Students who take part in the study will do so at school during the school day.

5. Taking part is voluntary and by taking part in this SPIT project your child will miss about 5 minutes of regular class.

6. You can take your child out of the study if you decide that you do not want them to take part. Your child has the right not take part in answering any of the questions if they do not want to.

7. Any information you give us is confidential. No individual information will be reported and no parent or child will be identified by name anywhere in the study. The only people who will see the information from the study are instructors and graduate students involved in the study. A number will be used instead of your child’s real name so that there is no way anyone will know how your child did or that your child took part in the study.

8. All records will be stored in a locked filing cabinet in Maureen MacKinnon McQuarrie’s office. Test records will be shredded and the saliva (spit) will be thrown away after it has been tested.

9. By letting your child take part in this study, you may help to make learning easier for children. The study may help teachers understand how to help children learn better.

10. If at any time you have any concerns about your treatment or rights as a person taking part in this practice, you may contact the Research Subject Information Line in the UBC Office of Research Services at the University of British Columbia.

   The tasks are interesting and fun and most children like doing them. We appreciate your help. If you want to ask us anything you may call Dr. Linda Siegel or Maureen MacKinnon-McQuarrie at numbers written above.
Spit & Memory Consent Form

I understand that a UBC graduate student will collect 5 saliva samples from my child before during and after during the Math Project. I also understand that researchers will have access to my child’s scores on the math and memory testing in the Math Project that they are already participating in.

Saliva Samples:
_____ I DO give my consent and agree for my child to give the saliva samples.
_____ I DO NOT give my consent and DO NOT agree for my child to give the saliva samples.

Memory and Math Testing
_____ I DO consent for my child to answer memory and math questions and allow researchers to access my child’s test scores.
_____ I DO NOT consent for my child to answer memory and math questions and to have access and use my child’s test scores in this research.

Your Name (please sign your name):

Your Name (please print your name):

Today’s Date:

Your Child’s Name (please print):

Your Child’s Birth Date:

When you sign this it means that you have received a copy of this consent form (Pages 1 & 2) for your own records.

THANK-YOU

Funded by: Social Sciences and Humanities Research Council
APPENDIX D

THE UNIVERSITY OF BRITISH COLUMBIA

ASSENT FORM

Children aged 7-13 years

SPIT & MEMORY

Please read this form to the student.

I am being asked to give a little bit of my spit before and after I do some reading, adding and subtracting, and remembering numbers. I understand that I do not have to do this unless I want to. I can stop anytime if I decide that I do not want to do this.

The reading, adding, and remembering numbers is just like what I do in school everyday.

Giving some spit means that a student from UBC will give me something to chew on that is like a piece of gum, only it has no taste. I will chew it, just like gum for about 1 minute and will be careful not to swallow it. After 1 minute the student from UBC will take it from me. This will happen 5 times during the study.

I ____________________________, understand that I am giving 5 samples of my spit, that I will be asked to remember some numbers, do some adding questions and my math and test scores are being accessed and used in this research.