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# Reactivity to Stress and the Cognitive Components of Math Disability in Grade 1 Children

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## Abstract

This study investigated the relationship among working memory, processing speed, math performance, and reactivity to stress in 83 Grade 1 children. Specifically, 39 children with math disability (MD) were compared to 44 children who are typically achieving (TA) in mathematics. It is the first study to use a physiological index of stress (salivary cortisol levels) to measure children's reactivity while completing tasks that assess the core components of MD: working memory for numbers, working memory for words, digits backward, letter number sequence, digit span forward, processing speed for numbers and words, block rotation, and math tasks. Grade 1 children with MD obtained significantly lower scores 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 for Grade 1 children, regardless of math ability. Grade 1 children with MD and higher reactivity had significantly lower scores on the letter number sequence task than the children with MD and low reactivity. The findings suggest that high reactivity impairs performance in working memory and math tasks in Grade 1 children, and young children with high reactivity may benefit from interventions aimed at lowering anxiety in stressful situations, which may improve learning.

### Keywords

math disability; working memory; processing speed; children; reactivity to stress; cortisol

Math disability (MD) affects between 5% and 8% of school children (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. Therefore, it is important to understand the underlying processes that contribute to MD and to design interventions to target these difficulties.

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## Core Cognitive Processes in Math Disability

A significant body of literature indicates that children with MD exhibit a deficit in the working memory system (Baddeley, 1986; Baddeley & Hitch, 1974) that includes the central executive (i.e., attention system involved in the simultaneous processing and storage of information), phonological loop (i.e., short-term storage system for speech-based information), and visuospatial sketchpad (i.e., short-term storage system for visuospatial information). Working memory deficits are believed to interfere with 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).

Also, processing speed (the ability to name numbers or pictures rapidly) has been investigated as a possible core deficit in children with MD (Geary, Hoard, Byrd-Craven, Nugent, & Numtee, 2007; Hecht, Torgesen, Wagner, & Rashotte, 2001; Passolunghi & Siegel, 2004). The results of this research have been mixed. Some studies indicate processing speed for numbers is impaired in children with MD (Bull & Johnson, 1997; Geary et al., 2007; Hitch & McAuley, 1991; Swanson & Jerman, 2006), whereas other studies have not found a processing speed impairment for numbers or words in children with MD (Geary, 1990; Geary, Brown, & Samaranayake, 1991; Geary, Hamson, & Hoard, 2000; Passolunghi & Siegel, 2004). Swanson and Beebe-Frankenberger (2004) found processing speed does not contribute unique variance to the model when reading ability and nonverbal intelligence are partialed out, and Geary et al. (2007) found that processing speed was impaired only in the children with the most severe MD.

This study addresses several major limitations that may be the cause of equivocal findings in previous research on MD. First, some 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 children who are typically achieving (TA) in math (Geary et al., 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 are TA in math. Therefore, we tried to limit our sample to children with MD only and compare them to their TA peers to identify the core cognitive components of MD in young children. Second, some previous studies have used high cutoff scores (e.g., including children scoring at the 46th percentile and below on standardized math tests) to identify participants with MD, which includes children functioning within the average range in mathematics (Geary, 1990; Geary et al., 1991). We used more stringent criteria in participant selection. Finally, the preponderance of the research on MD has focused on older children, whereas our study focuses on children in Grade 1.

## Math Anxiety

Math anxiety has been investigated as a factor that contributes to difficulty in executing math computations by interrupting working memory. Richardson and Suinn (1972) described math anxiety as the arousal or apprehension associated with the manipulation of numbers in academic, private, and social environments. It is a negative reaction that causes a feeling of tension and anxiety in situations where the manipulation of numbers, calculations, or math problem solving is required. 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 math tasks. Students with self-reported high math anxiety consistently perform more poorly on mathematics achievement tests than do students with low math anxiety (Ashcraft & Faust, 1994; Ashcraft, Kirk, & Hopko, 1998; Ashcraft & Kirk, 2001; Faust, Ashcraft, & Fleck, 1996; Hembree, 1990; Hopko, Mahadeven, Bare, & Hunt, 2003; Mattarella-Micke, Mateo, Kozak, Foster, & Beilock, 2011).

Math anxiety has been considered a performance-based disorder that is similar to anxiety disorders such as social phobia and test anxiety (Hopko, McNeil, Zvolensky, & Eifert, 2001). Performance-based anxiety disorders are characterized by the experience of anxiety and/or physiological arousal in the immediate context of a performance-based or timed setting or in anticipation of having to perform (Ashcraft, Krause, & Hopko, 2007). However, math anxiety has been shown to be conceptually distinct from other forms of anxiety. For example, math anxiety exists in individuals who do not have general anxiety or trait anxiety (Ashcraft et al., 2007), and correlations among measures of math anxiety are higher (from .50 to .80) than are correlations between measures of math anxiety and measures of general anxiety (.35), trait anxiety (.38), and state anxiety (.42). Ashcraft and Moore (2009) contend that whenever an individual with math anxiety is asked to perform math in a timed or high-stakes situation, the individual experiences arousal and an affective drop in math performance. According to some researchers, any math test arouses anxiety for the math anxious student (Hopko et al., 2003).

Our study placed young children in a performance-based situation designed to elicit the stress response for those with math anxiety. Participants were informed that they would be performing tasks involving numbers. Their physiological arousal or response to stress was indexed by collecting salivary cortisol levels before and after the stress-inducing situation. An increase in cortisol levels after testing signaled a stress reaction. Cortisol levels were measured at the start of testing to provide a measure of circulating cortisol 20 minutes before children were introduced to the math tasks or high-stakes situation. The second sample, taken 30 minutes after the start of testing, provided a measure of the increase in cortisol that presumably occurred as a result of being placed in the performance-based situation involving math tasks. According to Dickerson and Kemeny (2004), collecting salivary cortisol samples 21 to 40 minutes after the stressor samples the largest cortisol response. The physiological arousal that occurred in the immediate context—anticipation of being asked to perform math tasks—was assumed to be the result of math anxiety for the participants with high reactivity. Our goal was to investigate whether or not physiological arousal or high reactivity to stress affected performance on the tasks believed to contribute to mathematical competency in young children.

The math anxiety research findings are consistent with those of studies indicating that experiences involving social evaluation (e.g., public speaking; Kirschbaum, 1993) can activate the stress response so that it interferes with retrieval and encoding of information associated with the declarative memory system (i.e., the memory system responsible for storing facts, such as math facts or events). In fact, research has indicated that low and high levels of stress disrupt cognitive processing (Elzinga & Roelofs, 2005; Kirschbaum, Wolf, May, Wippich, & Hellhammer, 1996; Kuhlmann, Kirschbaum, & Wolf, 2005; Lupien, Gillin, & Hauger, 1999; Traverniers, Van Ruysseveldt, Smeets, & von Grumbkow, 2010) and moderate increases in stress followed by decreases in stress enhance cognitive processing (Blair, Granger, & Razza, 2005).

In math, researchers have observed a negative relationship between self-reported math anxiety and math performance; as self-reports of math anxiety increase in high school and college students, their math performance decreases (Ashcraft & Faust, 1994; Ashcraft & Krause, 2001; Faust et al., 1996; Hembree, 1990; Hopko et al., 2003; Mattarella-Micke et al., 2011). It has been suggested that the arousal of anxiety creates a reduction in the availability of working memory capacity by slowing 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). A recent study using physiological evidence of arousal and self-reports of math anxiety (Mattarella-Micke et al., 2011) examined the relationship among physiological response (cortisol arousal), math performance, and working memory in university students. The researchers found that for individuals with high working memory and high math anxiety, the higher their cortisol response, the poorer their performance on math tasks. They concluded that performance on math tasks for individuals with higher level working memory and high physiological response depends on the presence of math anxiety. They found no effect of cortisol arousal or math anxiety for lower working memory individuals.

Altogether, research has demonstrated that students with high math anxiety have lower scores on computational tasks or standardized math tests than students with low math anxiety (Ashcraft et al., 1998; Ashcraft & Faust, 1994; Ashcraft & Kirk, 2001; Faust et al., 1996; Hembree, 1990; Hopko et al., 2003; Mattarella-Micke et al., 2011). The preponderance of studies linking math anxiety to math performance have been conducted with older students and used self-report methods. Given math anxiety's debilitating and cumulative effects, it seems prudent to assess whether and how math anxiety may affect/ interrupt learning in young children, especially for those with MD.

## Math Anxiety in Young Children

One study (Krinzinger, Kaufman, & Wilmes, 2009) investigated math anxiety with early primary children ranging from Grade 1 to Grade 3, using the *Math Anxiety Questionnaire*

(Thomas & Dowker, 2000), a self-report instrument with a 5-point rating scale for difficulty of math items completed. The authors did not find any effect of math anxiety on calculation ability in young children. This finding may have been a result of the limitations of self-report measures, especially for use with young children (Cain & Dweck, 1995; Perry & Vanderkamp, 2000; Winne & Perry, 2000). Our study is one of a very few to focus on young children (Grade 1) and the first to examine the link between anxiety and math performance in young children suspected of having a math learning disability using a physiological index of stress. Our study joins a growing body of research focusing on physiological indices of stress. Specifically, we measured cortisol levels in children's saliva to investigate whether and how changes in cortisol levels are associated with cognitive processes, particularly those involved in math performance.

The arousal of anxiety may play a role in the working memory deficits of children with MD, and children with MD may be more vulnerable to experiencing anxiety because of their experiences with difficulty in learning. Ashcraft and Krause (2007) developed a model of risk factors for the development of math anxiety that suggests children with MD may be at higher risk of math anxiety because of their (a) low skill in math, (b) inadequate motivation, and (c) insufficient working memory. Our study focuses on young children with MD and investigates how high reactivity is related to performance on the cognitive tasks believed to underlie MD.

## Physiological Aspects of Stress and Cognitive Processing

The adrenal cortex produces cortisol, a glucocorticoid (GC) hormone that is released in response to perceived stress. There are two major influences on cortisol levels at any given time. The first influence is the circadian rhythm. Cortisol shows a circadian pattern of secretion over the daily 24-hour cycle, with the highest levels in the morning followed by a decline throughout the day toward the lowest levels, which occur during sleep. For the average person, normal circadian levels of cortisol at 8 a.m. can range from 3 to 20 ug/dL, with the average ranging from 10 to 12 ug/dL. By late afternoon, cortisol levels decrease by half from the morning levels and continue to decline to their lowest level after midnight (Aaron, Findling, & Tyrrell, 2004). The second major influence is the individual's responsiveness or reactivity to stressors. Research indicates that individuals vary in their reactivity to environmental stress according to their individual early developmental experience and inherited variation in the reactivity of the stress system (Boyce & Ellis, 2005; Traverniers et al., 2010).

High levels of cortisol affect neuronal activity in the hippocampus and prefrontal cortex, areas of brain that are critical in declarative learning and memory (deKloet, Oitzl, & Joels, 1999). The consolidation and retrieval of arithmetic facts, working memory, and the learning of novel semantic information, such as math facts, are dependent on the declarative memory system. Indeed, studies have demonstrated that adults with significantly elevated cortisol levels in response to stress or emotional arousal have impaired performance in working memory (Elzinga & Roelofs, 2005; Lupien et al., 1999; Mattarella-Micke et al., 2011; Oie, Everaerd, Elzinga, Van Well, & Bermond, 2006; Traverniers et al., 2010), retrieval of semantic memory (Buchanan & Lovallo, 2001; Kirschbaum et al., 1996; Kuhlmann, Kirschbaum et al., 2005; Kuhlmann, Piel, & Wolf, 2005; Lupien & Lepage, 2001), and spatial memory tasks (Lupien et al., 2005; Traverniers et al., 2010). Moreover, it appears that the effect of cortisol on cognitive function is bidirectional or reciprocal. That is, cortisol can affect cognitive function (e.g., working memory), and cognitive processing (e.g., the negative ideation associated with anxiety), in turn, has an effect on cortisol production. By contrast, the nonde-clarative memory system or procedural memory, involving the prefrontal cortex (PFC), basal ganglia, and cerebellum (Ullman, 2004), supports memory for skills such as bike riding, habits, and associative memory but is not linked to stress-induced impairments.

Impairment in memory because of excessive cortisol is believed to be caused by the activation of the corticosteroid receptors (i.e., type I or mineralocorticoid receptors [MRs] and type II or glucocorticoid receptors [GRs]) (Lupien & McEwen, 1997). MRs are known to have a high affinity for cortisol and are found in high densities primarily in limbic system structures such as the hippocampus. MRs are substantially occupied or saturated even at low basal cortisol levels, indicating primarily a permissive or tonic influence on basal cortisol activity. GRs are known to have a lower affinity for cortisol and are widely distributed in the brain, not only in limbic structures but also in areas such as the PFC. GRs are only partially occupied at low basal cortisol levels and become progressively saturated at the circadian peak or after stress, suggesting a role related primarily to suppression of stress-induced cortisol activity. Of importance, MRs and GRs interact, and shifts in the balance between MRs and GRs can alter the set point of stress system activity. Moreover, it is believed that the ratio of saturation of these receptors affects not only neurons in the hippocampus and PFC but also declarative memory performance (deKloet et al., 1999). Optimal memory levels occur when MRs are fully saturated and GRs are partially saturated (cortisol is at basal levels or mildly elevated), whereas memory processes are impaired when GRs as well as MRs are fully saturated (cortisol at stress levels or highly elevated). The MR saturation theory is consistent with Yerkes-Dodson (1908) law, which predicts an inverted U-shaped function between arousal and performance (Abercrombie, Kalin, Thurow, Rozenkranz, & Davidson, 2003).

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. This study examines this possibility by examining whether children with MD have higher reactivity (measured by the change in cortisol levels during testing) compared to their TA peers.

Most of the research linking cortisol levels to problematic performance involve adult participants. However, one study (Jimerson, Durbrow, Adam, Gunnar, & Bozoky, 2006) examined the relationship among academic achievement, attention problems, and cortisol levels in 86 children ages 5 to 12, living in a rural Caribbean village. The results indicated that for children with inattention-internalizing problems, there was a significant association between high cortisol levels and poorer academic performance. One recent study with children aged 8–10 years of age (Quesdada, Wiemers, Schoofs, & Wolf, 2012) used physiological measures (cortisol levels) and self-reports to assess children’s response to psychosocial stress and to investigate delayed memory retrieval and working memory for verbal and non-verbal information after a psychosocial stressor (*Trier Social Stress Test for Children*) or a nonstress condition. They found that children had the same stress response as adults (elevated cortisol) after exposure to the stress condition. The children who elicited a higher cortisol response after the stress condition committed more errors on the delayed memory task, but they did not find an effect of stress on working memory. Therefore, our study examines whether children with high reactivity or children with both MD and high reactivity perform more poorly on tasks that involve executive function, working memory for numbers, words, and visuospatial information, and math tasks.

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, Piel, et al., 2005; Kuhlmann, Kirschbaum, et al., 2005; Maheu, Collicut, Kornik, Moszkowski, & Lupien, 2005). For individuals with math anxiety, math tasks or tasks involving the manipulation of numbers can be considered emotional information as they evoke 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.

Also, the literature indicates that an individual’s response to a stressor varies according to his or her perception of the degree of threat (Boyce & Ellis, 2005). Children with MD may be more susceptible to experiencing stress in school because of their learning difficulties, because of their more frequent experience with failure, and because they are placed alongside their TA peers who do not experience the same difficulties. However, this hypothesis has not been tested. 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 found that children with learning disabilities learning in the regular classroom had more failure attributions, poorer academic self-concept, and more anxiety. Therefore, our study examines whether children with MD have higher reactivity to stress than their TA peers.

Finally, our study extends research concerning stress and performance in several ways. Most studies investigating relationships between stress and performance have taken place in laboratory settings. Our study took place in a naturalistic context (school). Some studies have employed standardized tasks such as digit span and paragraph recall, and others have used nonstandardized tasks such as learning a list of words for later recall, or recall of events in a film. Our study examined young children’s performance on a comprehensive set of math and working memory tasks, all with standardized administration protocols. Most studies with school-aged populations have relied on self-reports of anxiety. Our study built on recent research using physiological markers of stress (e.g., cortisol) in the context of completing working memory and short-term memory tasks. Finally, the preponderance of studies investigating the effects of stress on the declarative memory system have involved adults. Our study builds on the small number of studies that have examined the relationship between stress in children and learning.

## Overview of Our Study

Our 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 children who are TA in math. Second, it examined the relationship between stress and the cognitive processing deficits of children with MD. We tested the hypothesis that high reactivity would disrupt the processes believed to underlie MD and that high reactivity would be an even greater problem for children with MD than it is for their TA peers.

Specifically, our study was designed to address four research questions:

> *Research Question 1*: Do Grade 1 children with MD differ from their TA peers in terms of their performance on working memory, processing speed, and math tasks?

We predicted that children with MD would exhibit significantly lower scores on working memory for numbers, letter number sequence, digits backward, and 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)

> *Research Question 2*: Does reactivity to stress affect Grade 1 children’s performance on working memory, processing speed, and math tasks?

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

> *Research Question 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 rhythms compared to their TA peers?

We hypothesized that children with MD would have higher levels of reactivity during testing. This hypothesis was based on research findings with adults that indicate high reactivity impairs performance on working memory and declarative memory tasks.

> *Research Question 4*: Does reactivity affect children with MD and TA children differently in terms of their performance on working memory, processing speed, and math tasks compared to their TA peers? Does reactivity exacerbate performance deficits within the MD group?

We 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. However, we also predicted that children with MD and high reactivity would experience the greatest performance deficits.

## Method: Participants and Setting/Context

A total of 83 Grade 1 children (42 females), ranging in age from 6 to 7.3 years ($M = 6.5$, $SD = 0.47$), participated in this study. Of these children, 10.8% were first-generation immigrants to Canada and reported their first language as one other than English. Screening measures (described below) were used to assign children to one of two groups: the MD group ($n = 39$)

and the TA group (*n* = 44). Children from cultural and linguistic minority groups were approximately equally divided between the MD and TA groups. Descriptive statistics for the demographic variables and screening measures are shown in Table 1. The average age for the children who were classified as MD was 6.6 years (*SD* = 0.47), and the average age of children in the TA group was 6.56 years (*SD* = 0.47). The study took place in a school district in a western province of Canada, which serves the full range of socioeconomic statuses, ethnically and linguistically diverse communities (approximately 30% of children within the school district are English language learners), and learners having a range of needs and abilities. Children with identified behavior or emotional classifications were not included in the study.

## Measures

### Measures in the Screening Phase

During the screening phase, four subtests from the *Woodcock–Johnson Tests of Achievement–Third Edition* (WJ-III ACH; Woodcock, McGrew, & Mather, 2001) were administered to screen students for MD and to identify a TA comparison group.

**Applied problems—**The Applied Problems subtest (WJ-III ACH; Woodcock et al., 2001) examines children's ability to solve mathematical problems through the application of quantitative reasoning skills. The applied problems task requires comprehension of a math problem and the ability to identify important information and then perform the calculation. For example, the child is shown a picture and asked a question about the picture (e.g., "How many apples are there in this picture?"). The spilt-half reliability coefficient for this task is .93.

**Math calculation—**The Math Calculation subtest (WJ-III ACH; Woodcock et al., 2001) is an untimed task 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 (split-half reliability coefficient = .86).

**Letter-word identification—**The Letter-Word Identification subtest (WJ-III ACH; Woodcock et al., 2001) tests children's abilities to decode words presented in isolation. The subtest requires children to identify and read isolated words of increasing difficulty, for example, *is, the, and, from, keep, their, which, would* (split-half reliability coefficient = .94.

**Word attack—**The Word Attack subtest (WJ-III ACH; Woodcock et al., 2001) requires children to pronounce phonetically regular pseudowords, for example, *nat, ib, fim, jop, floxy, leck, pawk, distrum* (split-half reliability coefficient = .87).

**MD and TA classification—**Children were identified as having MD if they scored at or below the 25th percentile on the math calculation or applied problems tasks and above the 30th percentile on both the word attack and word identification tasks. Children who scored below the 30th percentile on either of the reading subtests were excluded from both the MD group and the TA groups. Children with scores above the 40th percentile on all four of the screening sub-tests and who matched children in the MD group in terms of sex, age, grade, language, and school were selected as the comparison (TA) group.

## Memory Measures in the Second Phase

The second phase of the study involved the administration of the nine cognitive tasks believed to underlie MD and the collection of the cortisol saliva samples from the selected participants. Nine tasks were administered to investigate the cognitive components of MD (working memory, processing speed, visuospatial skills, and math tasks), and four saliva samples were collected to determine whether stress was interfering with these processes.

## Working Memory

Working memory is composed of the central executive and two passive storage systems, the phonological loop and the visuospatial sketchpad (Baddeley, 1986; Baddeley & Hitch, 1974). The working memory tasks selected for this study are based on Baddeley and Hitch's model of working memory, which stresses the central executive or attention system that maintains memory representations in the face of interference (for a full discussion of these tasks, see Conway et al., 2005).

**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 to assess working memory or visual counting memory under memory load. The pattern used for the stimuli is a field of yellow and blue dots that are randomly placed on 30 × 20 cm white index cards. The instructions are, "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 child 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 is reached and the testing is terminated when the student fails all items in a set.

**Working memory for words—**Siegel and Ryan (1989) developed the working memory for words task. During this task the researcher says, "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 listens 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 _____"). After all sentences in a set are read and completed, the participant repeats the words that completed the sentences in the correct order; the response is considered correct if the participant repeats the words in the correct order. The test consists of 12 sets of sentences of increasing difficulty. The test begins with two sets of two sentences followed by three sets of three, four, and five sentences. Two practice sets are presented to the child to ensure he or she understands the task. Testing stops when the child fails all items at a level.

**Digit span backward—**This is a two-trial complex working memory span task that consists of eight items (*Wechsler Intelligence Scale for Children–Fourth Edition*; WISC-IV; Wechsler, 2003). During this task, a child listens to digits being read aloud at the rate of one digit per second. At the end of each list of digits, a child must recite the numbers he or she heard in reverse order. The split-half reliability coefficient for this task is .87.

### Short-Term Memory or Phonological Loop

**Digit span forward—**The digit span forward task is from the WISC-IV (Wechsler, 2003) and is designed to measure children's phonological/short-term storage or short-term memory storage. A child hears a list of digits at the rate of one digit per second. After listening to the series of numbers, the child is required to repeat the digits in order of presentation. The test score is the maximum total number of correct answers. The split-half reliability coefficient for this task is .87.

**Letter number sequence—**This task is from the WISC-IV (Wechsler, 2003) and is a complex dual task processing task that measures children's working memory for numbers and letters. It requires a child to store a set of numbers and letters and manipulate them into a sequence. During this task the child is read a sequence of numbers and letters and is asked to remember the numbers and letters and repeat back the numbers in ascending order and the letters in alphabetical order. This task has a split-half reliability coefficient of .90.

### Processing Speed

**Rapid picture naming—**As part of the *Woodcock–Johnson Tests of Cognitive Abilities–Third Edition* (WJ-III COG; Woodcock et al., 2001), the rapid picture naming tasks consists of 120 items that measure processing speed for naming common nouns. Children are presented with a page with pictures of common items and are asked to name the pictures as quickly as they can within 2 minutes (split-half reliability coefficient = .98).

**Rapid number naming—**The rapid number naming task contains 25 items. During the task, children are required to name a series of single-digit numbers from one to nine. The single-digit numbers are presented in a random order with five rows and five columns. The score is recorded as the time in seconds it takes the child to name all the numbers.

### Visuospatial Skills

**Block rotation—**The block rotation consists of 24 items and is a standardized subtest from the WJ-III COG (Woodcock et al., 2001) that measures a child's ability to solve visuo-spatial working memory mental rotation tasks. The child is shown a drawing with a choice of five drawings below it. Two of the drawings in the multiple-choice format are the same as the item presented. The examiner points to the drawing and states, "Look at this drawing, it looks just like this drawing and this drawing." The child is then presented with a series of pictures of three-dimensional visual patterns and asked to select from a multiple-choice format 2 three-dimensional pictures that match the stimulus but have been changed in spatial orientation. Reliability estimates are not reported in the technical manual.

## Math Performance

**Number series—**The Number Series subtest (WJ-III COG; Woodcock et al., 2001) measures mathematics knowledge and quantitative reasoning. During this task a child is presented with a series of numbers with one number missing in the set and he or she provides the number that completes the sequence, for example, 2, 4, __, 8; __, 3, 5, 7; 6, 5, 4, __; 2, 4, 6, __.

**Quantitative concepts—**The Quantitative Concepts subtest (WJ-III COG; Woodcock et al., 2001) consists of 34 items and provides 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, for the first item the child is presented with a picture of two dogs and the examiner reads, "How many dogs are there?" For another question the examiner says, "Listen. What number comes between three and five?" The ceiling level is reached after a child has received scores of 0 on four consecutive items (split-half reliability coefficient = .91).

## Cortisol and Circadian Rhythm Measures

To obtain information about each child's cortisol levels, saliva was collected using half-inch cotton rolls that children chewed until fully saturated. The wet cotton roll was placed into a labeled vial for storage at −20°C until assayed. Cortisol samples were collected four times over the course of the study: Time 1 (T1), prior to Phase 2 testing, to establish a pretest baseline; Time 2 (T2), 30 minutes posttest, as an index of the stress response; and on a separate day, in the morning (Time 3; T3) and afternoon (Time 4; T4), to assess the circadian rhythm on a typical day (i.e., a day without engaging in tasks designed to elicit math anxiety).

**Cortisol assay—**Cortisol was assayed using the Salimetrics Expanded Range High Sensitivity Salivary Cortisol Enzyme Immunoassay Kit (Salimetrics LLC, Philadelphia, PA). This is a sensitive assay designed to measure human salivary cortisol levels using an aliquot of 25 ug/dL saliva per tube. This assay is designed to be valid in experimental situations where interference may occur through collection techniques that affect pH, such as the consumption of food or drink. Assays were conducted in the laboratory of Dr. J. Weinberg at the University of British Columbia.

**Cortisol reactivity—**The difference between cortisol levels at T1 (pretest) and T2 (posttest; T2–T1) was used as the measure of reactivity for each participant. The reactivity index was divided into quartiles, and then three categories of stress were identified (high = at or above the 75th percentile, low = at or below the 25% percentile, and moderate = within the 2nd and 3rd quartiles). This is consistent with previous studies that have used the top quartile as the "gold standard" for high reactivity (Ellis, Essex, & Boyce, 2005) and research with children, which suggests the proportion of high reactivity status is approximately 20%

(Kagan, Reznick, & Snidman, 1988). The categorical index marker of stress was used to interpret the magnitude of the effect of stress reactivity on performance (effect size calculation). An example of the range of values associated with a participant from each of the categories is as follows: low reactivity = −.4059 to −.1357, moderate reactivity = −.1269 to .0921, and high reactivity = .0985 to .5934.

**Circadian rhythm—**The change in cortisol levels from T3 (a.m.) to T4 (p.m.) was computed (T4–T3), and the decrease from a.m. to p.m. was used as an index of the circadian rhythm for each participant (i.e., as a measure of changes in cortisol levels under normal conditions, without the stress of testing or difficult tasks).

## Procedures

In total, 932 Grade 1 children from 29 elementary schools completed the screening battery consisting of the Math Calculation, Applied Problems, Word Identification, and Word Attack subtests of the WJ-III ACH (Woodcock et al., 2001). Based on the results of the screening, 107 students were selected to participate in the study and assigned to either the MD or TA group.

A second consent form was sent home to parents whose children were selected for the study, explaining the purpose and process for collecting saliva samples. After consent was obtained, research assistants visited schools to collect data for participating children during two 40-minute testing sessions on Day 1. Students participated in one of the two testing sessions; the first session began at 1:00 p.m., and the second session followed at 1:40 p.m. During the testing session, children met individually with one of the research assistants in a private testing room outside their classrooms. After introducing themselves, the research assistants read the child an assent form to explain the study and what was involved. Verbal assent was obtained from children under the age of 7, and children 7 years of age and older printed their name to indicate consent.

During the testing session, measures were administered in the following order: saliva sample T1, working memory for numbers, working memory for words, digit span (WISC-IV; Wechsler, 2003), letter number sequence (WISC-IV; Wechsler, 2003), quantitative concepts (WJ-III ACH; Woodcock et al., 2001), rapid picture naming (WJ-III; Woodcock et al., 2001), block rotation (WJ-III; Woodcock et al., 2001). Saliva sample T2 was collected 30 minutes from the start of testing. This is consistent with previous research indicating that cortisol collection that occurs 21 to 40 minutes from the start of the stressor reflects the largest response (Dickerson & Kemeny, 2004). Also, stress studies suggest that it is easier to detect a stress response in the afternoon, when basal cortisol levels are lower, than in the morning, when basal cortisol levels are naturally elevated (Dickerson & Kemeny, 2004). Furthermore, research indicates that salivary cortisol levels measured 30 minutes posttask are an accurate physiological measure of circulating cortisol levels during the task (Kirschbaum & Hellhammer, 2000). Our study took place in the afternoon and collected saliva samples 30 minutes from the start of the stressor.

The researchers returned to the school the day following the testing session (Day 2)—a day when no testing occurred—to collect two additional saliva samples: T3 between 9:00 and

9:30 a.m. and T4 at 2:45 p.m. These samples were taken as an estimate of children's normal circadian rhythm (basal hormone levels in the absence of a stressor). After the testing session and saliva sample collection, the research assistants led children back to their classrooms and thanked them for their participation in this study. In total, data collection spanned 40 minutes on Day 1 for each participant.

## Results

The results are organized to address each of the research questions. Effect sizes are reported as Cohen's *d*, which were corrected with Hedges's *g* (1985) to gauge the magnitude of the effect.

### Do Grade 1 Children With MD Differ From Their TA Peers in Terms of Their Performance on Working Memory, Processing Speed, and Math Tasks?

A series of univariate analyses of variance (ANOVAs) were conducted to examine differences in performance between children with MD and their TA peers on the nine cognitive tasks. A Bonferroni correction was applied to adjust for familywise Type I error, and significance was accepted at $p < .005$ (.05/9 = .005). Table 2 displays the means and standard deviations for the working memory, processing speed, and math concepts tasks, the ANOVA results, and the corresponding effect sizes.

Statistically significant differences were found between Grade 1 children with MD and their TA peers on the letter number sequence task and the quantitative concepts task. Specifically, children with MD performed significantly more poorly than their TA peers on the letter number sequence task and the magnitude of the effect was at the high end of the moderate range, $F(1, 81) = 13.67$, $p < .01$, $d = -0.77$. Similarly, Grade 1 children with MD scored significantly lower than their TA peers on the quantitative concepts task, and the effect size for this difference was large, $F(1, 81) = 35.63$, $p < .01$, $d = -1.30$. An examination of mean scores for working memory and processing speed indicates that scores for children with MD were numerically lower than those for TA children, although the differences were not statistically significant.

### Does Reactivity to Stress Affect Grade 1 Children's Performance on Working Memory, Processing Speed, and Math Tasks?

This question was answered by conducting a series of bivariate and multiple linear regression analyses where MD and TA and reactivity were the predictor variables and performances on each of the nine tasks were the criterion variables. The contribution of reactivity to the regression models was examined, and results are presented in Table 3.

Categories of low, moderate, and high reactivity were created to calculate effect sizes for the interpretation of the influence of reactivity on performance on the cognitive tasks (see Table 4). There were 11 children in the MD group and 10 children in the TA group whose cortisol changes from T1 to T2 ranged from slight decreases to increases equal to or below the first quartile (−.4059 to −.1357); they were classified as the low reactivity group. There were 17 children with MD and 24 TA children with cortisol increases above the first quartile and below the third quartile (−.1269 to .0921); they were classified as the moderate reactivity group. Finally, there were 11 children with MD and 10 TA children with increases in cortisol equal to or greater than the fourth quartile (.0985 to .5934); they were classified as the high reactivity group. Effect sizes were calculated by comparing the mean difference in performance between low and high reactivity groups divided by the pooled standard deviation for each of the tasks to provide meaningful interpretation of reactivity and performance on the tasks. Table 5 provides the descriptive statistics for the performance tasks by reactivity groups and the effect sizes for differences between high and low reactivity.

The results of the regression analysis indicated that reactivity was a statistically significant predictor of performance on the working memory for numbers task, $\beta = -2.52$, $t(83) = -2.59$, $p = .01$, with a corresponding moderate effect size ($d = -0.66$). The negative moderate effect size indicates that, on average, scores for children in the high reactivity group were 0.66 of a standard deviation lower than scores for the low reactivity group. In the bivariate regression analysis, reactivity explained approximately 7% of the variance in performance on the memory for numbers task, and in the multiple regression analysis approximately 13% of the variance could be explained by both MD and reactivity.

Reactivity was also a statistically significantly predictor of performance on the working memory for words task: $\beta = -1.83$, $t(83) = -2.22$, $p = .02$, with a corresponding large effect size ($d = -0.88$), indicating that the children with high reactivity obtained lower scores than the children with low reactivity. In the bivariate regression analysis, reactivity explained approximately 6% of the variance in scores for the working memory for words task, and in the multiple regression analysis, MD and reactivity explained approximately 11% of the variance for this task.

Finally, reactivity was a statistically significant predictor of performance on the quantitative concepts task, $\beta = 18.074$, $t(83) = -2.60$, $p = .01$, with a corresponding moderate effect size ($d = -0.55$) for high to low reactivity, indicating that the high reactivity group performed more poorly than the low reactivity group. In the bivariate regression analysis, reactivity explained approximately 6% of the variance in performance on the quantitative concepts tasks and in the multiple regression analysis 36% of the variance was explained by MD/TA and reactivity. Reactivity was not a statistically significant predictor of performance on any of the other tasks. Taken together, results of the regression analyses indicate that high reactivity predicts poorer performance on the working memory for numbers, working memory for words, and quantitative concepts tasks in Grade 1 children.

### 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 Rhythms Compared to Their TA Peers?

Descriptive statistics for absolute cortisol levels at times T1 through 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 6. Although the means for absolute cortisol levels, reflecting both reactivity and circadian rhythm, were higher at each time for the children with MD compared to the TA children, results of the independent *t* tests indicate that the differences were not statistically significant at any time. Specifically, these results indicate no statistically significant differences in cortisol levels between the children with MD and their TA counterparts for reactivity from T1 to T2 or from T2 to T4, or for circadian rhythm.

### Does Reactivity Affect Children With MD and TA Differently in Terms of Their Performance on Working Memory, Processing Speed, and Math Tasks?

For this question, the interaction between MD/TA and reactivity was examined to determine whether children with MD were differentially affected by reactivity than their TA peers. Children with MD did not perform differently than TA children on the nine tasks as a result of reactivity. The descriptive statistics are presented in Table 7 and indicate that the mean scores for children with MD and high reactivity are lower than those for children with MD and high reactivity on the working memory for numbers, working memory for words, digit span forward, digit span backward, rapid number naming, rapid picture naming, letter number sequence, and quantitative concepts tasks. TA children with high reactivity exhibited a similar pattern; that is, those with high reactivity performed more poorly than those with low reactivity on the working memory for numbers, working memory for words, rapid picture naming, and quantitative concepts tasks.

Table 8 presents the results of the interaction for MD/TA and reactivity for the performance tasks and the corresponding effect sizes. No statistically significant interactions for MD/TA and reactivity for the nine cognitive tasks were obtained.

### 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 to examine how reactivity affected performance within the MD group. A Bonferroni correction was applied to adjust for familywise Type I error, and significance was accepted at $p < .01$ (.05/5 = .01). Results indicated statistically significant differences in performance for children with MD by high and low reactivity on the letter number sequence task, $t(20) = 3.141$, $p = .005$. The high reactivity group obtained lower scores than the low reactivity group, and the effect size for this comparison was large ($d = -1.28$). No statistically significant differences were found between children with MD and high reactivity compared to those with low reactivity for the remainder of the cognitive tasks. These results provide evidence indicating that children with MD and high reactivity differ on the letter number sequence task from those with low reactivity. This is a task that is impaired in children with MD, and this finding indicates the high reactivity may exacerbate the learning problems children with MD already experience in this area.

## Discussion

Overall, we found that Grade 1 children with MD performed more poorly on the letter number sequence and quantitative concepts tasks than peers who are TA in math. We examined whether working memory impairments were attributable to domain general working memory impairment for numerical, verbal, and alphabetic information or a domain-specific impairment for numerical information only. The results indicated that children with MD did not exhibit a domain general working memory impairment. However, these findings need to be interpreted with caution. The MD sample likely included some false positives because of the inherent methodological difficulties in identifying a pure MD sample in young children. False positives occur because of the difficulty in discriminating between Grade 1 children with MD and Grade 1 children with low achievement in math that is not the result of an MD. Children with low math achievement in Grade 1 have not been consistently found to have low math achievement in Grade 2 (Geary, Hoard, & Hamson, 1999). The presence of false positives in the MD sample can affect results by inflating scores on tasks that are impaired in children with MD and lead to the conclusion that there are no differences between groups when true differences do exist. Nevertheless, our results corroborate previous research, which has indicated that children with MD have impairments in their working memory for numbers or on working memory tasks that involve the central executive (Hitch & McAuley, 1991; Siegel & Ryan, 1989).

Children with MD obtained significantly lower scores on the quantitative concepts measure compared to their TA peers. In other words, findings demonstrate that Grade 1 children with MD have significantly more difficulty with tasks associated with number sense, that is, cardinal ordering, counting, sequencing, and number series, than do their math TA peers. These results are consistent with those of studies indicating that young children with MD make more errors on counting tasks than do children who are TA (Geary et al., 1999; Geary et al., 2000; Jordan & Montani, 1997) and those of recent research that has found that early development of number sense is predictive of math achievement (Jordan, Glutting, & Ramineni, 2010).

Our research examined whether the phonological loop component of working memory was impaired in children with MD. To date, the phonological loop has been investigated in several studies because of its possible implication in the less efficient working memory performance of children with MD. The hypothesis is that children with MD have weaker working memory and do not develop basic number fact representations in long-term memory because of the rapid decay of information in short-term storage. The results of this study indicate that Grade 1 children with MD and children who are TA in math do not differ in terms of their capacity on the digit span forward task. Therefore, results provide evidence indicating that the phonological loop or short-term storage for small amounts of speech-based information (e.g., recalling numbers) is not impaired in children with MD. These findings are consistent with those of studies that have controlled for reading ability and have not found impairments on tasks that involve the phonological loop (Bull & Johnson, 1997; McLean & Hitch, 1999; Passolunghi & Siegel, 2004). Geary et al. (2000) found an impairment in digit span forward task in Grade 1 children with MD, but once IQ was partialed out, the differences were no longer significant. The studies that have found a reduced short-term storage capacity in children with MD have used older children (Hitch & McAuley, 1991; Passolunghi & Siegel, 2001; Siegel & Ryan, 1989), and one study did not control for RD (Geary et al., 1991). Future studies with young children may consider adding MD/RD and RD comparison groups to increase specificity toward math.

Reactivity to stress also predicted poorer performance on math tasks and working memory tasks involving numerical and verbal information in young children, regardless of MD status. In addition, Grade 1 children with MD and high reactivity performed significantly more poorly than children with MD and low reactivity on the letter number sequence task. Noteworthy is the finding that Grade 1 children with MD and high reactivity exhibited the poorest performance on the working memory for numbers, letter number sequence, and math tasks, although this finding did not reach statistical significance for the working memory for numbers and math tasks. Together these findings provide evidence that, as early as Grade 1, children's response to stress is related to their performance on working memory and math tasks. Children who have high levels of reactivity are likely to experience interference in their working memory, resulting in poor performance on the working memory and math tasks. Moreover, for children with MD, high reactivity may further impair already weak performance on working memory tasks. This possibility deserves attention in future research, particularly with older children who may elicit a stronger physiological response to stress.

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, Fayol, & Lathuliere, 1997; Geary, 2004; Passolunghi & Siegel, 2001, 2004). The finding that high reactivity significantly predicts performance on working memory tasks in both groups of Grade 1 children is also 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, Kirk, & Ashcraft, 2003). Our study is the first to provide physiological evidence for this relationship with young children. Ashcraft and Krause (2007) argued that the experience of anxiety causes a disruption in working memory that contributes to the poor execution of math computation and working memory in individuals with math anxiety. The reactivity findings are also theoretically and empirically consistent with the literature that has investigated stress and the declarative memory system in children (Blair et al., 2005).

These findings are important because working memory is a core component of mathematical competency, and a reduced capacity resulting from the stress response may limit children from meeting their learning potential. For Grade 1 children with MD, these findings are particularly important because they perform significantly more poorly than TA children on working memory tasks generally, and it appears possible that high reactivity can compound these difficulties.

Some research indicates that math performance and working memory deficits resulting from stress improve to the normal range when cognitive behavior intervention is provided for math anxiety (Hembree, 1990). Therefore, identifying children with high reactivity to stress and finding ways for helping them to cope with stress are important. Stress results in TA Grade 1 children experiencing some of the same difficulties as children with MD. Therefore, teachers need to consider stress as a source of difficulty, perhaps before or in addition to considering the possibility of a learning disability. Although research into the construct of reactivity is relatively new to education and physiological measures may not be practical in school settings, there are other ways to assess young children's stress that may prove helpful, including clinical interviews, parent rating scales, and observations. These tools are reliable alternatives to administering self-report questionnaires to young children and can gather information about intra- and interpersonal factors that lead to stress (e.g., perceived or actual ability, family circumstances). Ideally, triangulating data about stress and anxiety from multiple sources, including self-reports and teacher or parent observations, could assist researchers in identifying a purer math anxiety sample by reducing false positives for math anxiety, such as individuals with a vulnerability toward anxiety or state anxiety or those with an unidentified emotional disorder. Future studies could also assess participants' stress reactions in multiple contexts to assess their situatedness and may consider including covariates, for example, student characteristics and contextual factors.

Working memory tasks are included in psychoeducational assessments, and 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 incorrectly identify the student as having a process deficit in the area of working memory, when the student may actually have a high response to stress that is interfering with his or her ability to perform working memory tasks. Again, stress needs to be considered in assessments of children's working memory and overall cognitive ability, and future research should investigate how reactivity to stress might influence performance and deflate overall IQ scores.

In summary, the present study extends the existing MD literature and adds to the previous conceptual scheme of MD (Geary, 2004), which emphasizes the relationship between mathematical conceptual and procedural competencies and the supporting cognitive systems. Geary's (2004) conceptual scheme highlights the centrality of the central executive, a key component of working memory (Baddeley, 1986; Baddeley & Hitch, 1974) that controls the attentional and inhibitory processes for working memory, which in theory manifest as mathematical deficits in conceptual or procedural competencies. Also, our study is the first to examine how reactivity to stress influences performance on working memory (underlying cognitive system) and math tasks, using salivary cortisol as a physiological index of stress in young children. We show for the first time that young children with higher reactivity perform more poorly on working memory tasks and math tasks and that performance of children with MD was particularly affected by high reactivity on working memory tasks. Our findings suggest that young children's physiological reactivity to stress is an important variable to consider in assessing learning problems in math because of the involvement of working memory in 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. Research to investigate methods of reducing reactivity in young children to improve learning is an important avenue of future attention.

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## Table 1

Demographic Statistics and Screening Characteristics of Participants.

| **MD** | | **TA** | |
|---|---|---|---|
| Numbers | | Numbers | |
| Male | 18 | Male | 23 |
| Female | 21 | Female | 21 |
| Total | 39 | Total | 44 |
| Age | | Age | |
| *M* | 6.6 | *M* | 6.56 |
| Range | 6.0–7.3 | Range | 6.4–7.04 |
| *SD* | .47 | *SD* | .47 |
| Language | | Language | |
| English as a first language | 88% | English as a first language | 91% |
| English as a second language | 12% | English as a second language | 9% |
| Grade level | 1 | Grade level | 1 |
| Time in special ed. placement | 0 | Time in special ed. placement | 0 |
| Intelligence | | Intelligence | |
| *M* | 99 | *M* | 112 |
| Range | 74–122 | Range | 79–139 |
| Tests used WJ COG-III VCI | | Tests used WJ COG-III VCI | |
| Word Attack reading | | Word Attack reading | |
| *M* | 104 | *M* | 115 |
| *SD* | 9.27 | *SD* | 10.75 |
| Range | 94–130 | Range | 99–143 |
| Word identification | | Word identification | |
| *M* | 110 | *M* | 118 |
| *SD* | 9.14 | *SD* | 10.30 |
| Range | 79–122 | Range | 99–142 |
| Math calculation | | Math calculation | |
| *M* | 78 | *M* | 110 |
| *SD* | 23 | *SD* | 7.37 |
| Range | 73–118 | Range | 96–131 |
| Applied problems | | Applied problems | |
| *M* | 92 | *M* | 111 |
| *SD* | 9.10 | *SD* | 9.47 |
| Range | 73–118 | Range | 97–136 |
| Location | | Location | |
| Geographic region locale | Suburban | Geographic region locale | suburban |

Note: Tests used: For verbal comprehension, *Woodcock–Johnson Tests of Cognitive Abilities–III*; for word attack, word identification, math calculation, and applied problems, *Woodcock–Johnson Tests of Achievement–Third Edition*. MD = math disability; TA = typically achieving.

## Table 2

Working Memory and Processing Speed Tasks by Subgroup.

| | MD | | TA | | | |
|---|---|---|---|---|---|---|
| | ***M*** | ***SD*** | ***M*** | ***SD*** | ***F*** | ***d*** |
| Working memory for numbers | 3.28 | 1.61 | 4.05 | 1.67 | 4.48 | −0.46 |
| Working memory for words | 1.87 | 1.45 | 2.52 | 1.30 | 4.62 | −0.47 |
| Digit span forward | 6.97 | 1.87 | 7.77 | 1.61 | 4.36 | −0.45 |
| Digit span backward | 4.59 | 1.39 | 5.20 | 1.62 | 3.39 | −0.40 |
| Rapid number naming | 17.92 | 6.29 | 15.07 | 3.70 | 6.52 | −0.55 |
| Rapid picture naming | 99.62 | 14.06 | 105.50 | 13.90 | 3.82 | −0.42 |
| Letter number sequence | 7.23 | 2.70 | 9.61 | 3.12 | 13.67** | −0.77 |
| Quantitative concepts | 94.78 | 8.93 | 110.18 | 13.71 | 35.63** | −1.30 |
| Block rotation | 98.87 | 17.43 | 105.27 | 16.72 | 2.91 | −0.37 |

Note: Negative *d* indicates that children with MD obtained lower performance than TA children. MD = math disability; TA = typically achieving.

$^{**}p < .005$.

## Table 3

Regression Results for Reactivity Adjusted for MD and TA on the Working Memory and Processing Speed Tasks.

| | ***B*** | ***SE*** | **β** | ***t*** | ***p*** | $R^2$ | $R^{2*}$ | ***d*** |
|---|---|---|---|---|---|---|---|---|
| Working memory for numbers | −2.52 | 0.97 | −.27 | −2.59 | $01^*$ | .07 | .13 | −.66 |
| Working memory for words | −1.83 | 0.83 | −.23 | −2.22 | $.02^*$ | .06 | .11 | −.88 |
| Digit span forward | −0.86 | 1.07 | −.09 | −0.80 | .42 | .01 | .06 | .02 |
| Digit span backward | 0.23 | 0.94 | .03 | 0.25 | .81 | .00 | .04 | .14 |
| Rapid number naming | 3.48 | 3.12 | .12 | 1.12 | .27 | .02 | .09 | .09 |
| Rapid picture naming | 16.64 | 8.43 | −.21 | −1.97 | .05 | .04 | .09 | −.57 |
| Letter number sequence | −2.28 | 1.79 | −.13 | −1.27 | .21 | .02 | .16 | −.38 |
| Quantitative concepts | −18.07 | 6.95 | −.23 | −2.60 | $.01^*$ | .06 | .36 | −.55 |
| Block rotation | −3.16 | 10.53 | −.03 | −0.30 | .76 | .00 | .04 | .08 |

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 deviations in mean score according to group membership. $R^2$ indicates the percentage of variance in scores accounted for by reactivity after controlling for MD/TA. $R^{2*}$ indicates the percentage of variance in scores accounted by both MD/TA and reactivity. MD = math disability; TA = typically achieving.

$^*p < .05$.

## Table 4

Frequency Percentages for Cortisol Reactivity Classification.

| | | Low (−.4059 to −.1357) | | Moderate (−.1269 to .0921) | | High (.0985 to .5934) | |
|---|---|---|---|---|---|---|---|
| **Cortisol Reactivity** | **Group** | ***n*** | **%** | ***n*** | **%** | ***n*** | **%** |
| T1 to T2 | MD | 11 | 13.3 | 17 | 20.5 | 11 | 13.3 |
| | TA | 10 | 12.0 | 24 | 28.9 | 10 | 12.0 |

Note: MD = math disability; TA = typically achieving.

## Table 5

Descriptive Statistics for Performance Tasks and Reactivity Categories and Effect Size.

| | Low | | Moderate | | High | | |
|---|---|---|---|---|---|---|---|
| | ***M*** | ***SD*** | ***M*** | ***SD*** | ***M*** | ***SD*** | ***d*** |
| Working memory for numbers | 4.33 | 1.65 | 3.66 | 1.40 | 3.14* | 1.98 | −0.66 |
| Working memory for words | 2.62 | 1.28 | 2.37 | 1.47 | 1.57* | 1.25 | −0.88 |
| Digit span forward | 7.33 | 1.46 | 7.44 | 1.71 | 7.38 | 2.20 | 0.02 |
| Digit span backward | 4.95 | 1.02 | 4.78 | 1.73 | 5.14 | 1.59 | 0.14 |
| Rapid number naming | 16.52 | 4.57 | 16.54 | 5.78 | 16.05 | 5.01 | 0.09 |
| Rapid picture naming | 107.52 | 10.58 | 102.22 | 12.81 | 98.71 | 18.61 | −0.57 |
| Letter number sequence | 9.19 | 2.92 | 8.46 | 2.89 | 7.86 | 3.79 | −0.38 |
| Quantitative concepts | 108.10 | 15.01 | 101.85 | 13.10 | 99.95 | 13.88 | −0.55 |
| Block rotation | 102.10 | 15.45 | 103.15 | 17.55 | 100.71 | 19.03 | 0.08 |

Note: *d* is standardized mean difference for the high to low reactivity categories.

* $p < .05$.

## Table 6

Descriptive Statistics for the Absolute Cortisol Levels at T1 to T4, Cortisol Reactivity, and Circadian Rhythm.

| | **MD** | | | | **TA** | | | |
|---|---|---|---|---|---|---|---|---|
| **Cortisol Levels** | ***M*** | ***SD*** | **Min** | **Max** | ***M*** | ***SD*** | **Min** | **Max** |
| T1 | 0.13 | 0.09 | 0.05 | 0.48 | 0.10 | 0.05 | 0.04 | 0.26 |
| T2 | 0.12 | 0.08 | 0.06 | 0.46 | 0.10 | 0.04 | 0.04 | 0.24 |
| T3 | 0.32 | 0.29 | 0.07 | 1.5 | 0.29 | 0.19 | 0.06 | 0.68 |
| T4 | 0.13 | 0.20 | 0.04 | 1.3 | 0.09 | 0.05 | 0.04 | 0.24 |
| T1–T2 cortisol change | −0.00 | 0.07 | −0.15 | 0.22 | −0.01 | 0.04 | −0.10 | 0.08 |
| T2–T4 cortisol change | 0.00 | 0.21 | −0.30 | 1.17 | −0.01 | 0.04 | −0.10 | 0.08 |
| T3–T4 cortisol change | −0.19 | 0.21 | −1.2 | 0.06 | −0.20 | 0.18 | −0.56 | 0.06 |

Note: Negative values for ug/dL (micrograms per deciliter) reflect a decrease in cortisol levels. MD = math disability; TA = typically achieving.

## Table 7

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

| | **TA** | | | | | | | **MD** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Low** | | **Moderate** | | **High** | | | **Low** | | **Moderate** | | **High** | | |
| | ***M*** | ***SD*** | ***M*** | ***SD*** | ***M*** | ***SD*** | **TA *M*** | ***M*** | ***SD*** | ***M*** | ***SD*** | ***M*** | ***SD*** | **MD *M*** |
| Working memory for numbers | 4.80 | 1.47 | 4.00 | 1.38 | 3.40 | 2.27 | 4.05 | 3.91 | 1.75 | 3.18 | 1.33 | 2.82 | 1.77 | 3.28 |
| Working memory for words | 2.90 | 1.10 | 2.79 | 1.25 | 1.50 | 1.17 | 2.52 | 2.36 | 1.43 | 1.76 | 1.60 | 1.55 | 1.21 | 1.87 |
| Digit span forward | 7.40 | 1.35 | 7.92 | 1.47 | 7.80 | 2.20 | 7.77 | 7.27 | 1.61 | 6.76 | 1.85 | 7.00 | 2.23 | 6.97 |
| Digit span backward | 5.00 | 1.05 | 5.17 | 1.60 | 5.50 | 2.17 | 5.20 | 4.91 | 1.04 | 4.24 | 1.82 | 4.82 | 7.51 | 4.59 |
| Rapid number naming | 15.70 | 3.71 | 14.88 | 4.01 | 14.90 | 3.14 | 15.07 | 17.27 | 5.31 | 18.88 | 7.09 | 17.09 | 6.23 | 17.92 |
| Rapid picture naming | 107.70 | 11.22 | 106.00 | 11.94 | 102.10 | 20.35 | 105.50 | 107.36 | 10.51 | 96.88 | 12.40 | 95.64 | 17.27 | 99.49 |
| Letter number sequence | 9.50 | 3.20 | 9.38 | 2.85 | 10.30 | 3.83 | 9.61 | 8.91 | 2.77 | 7.19 | 2.48 | 5.64 | 2.06 | 7.23 |
| Quantitative concepts | 118.60 | 9.43 | 107.79 | 13.54 | 107.50 | 15.47 | 110.18 | 98.55 | 12.65 | 93.47 | 6.16 | 93.09 | 7.81 | 94.79 |
| Block rotation | 109.00 | 12.86 | 106.08 | 18.61 | 99.60 | 15.26 | 105.27 | 95.82 | 15.40 | 99.00 | 15.52 | 101.73 | 22.64 | 98.87 |

Note: MD = math disability; TA = typically achieving.

## Table 8

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

| | ***F*** | ***p*** | **TA (*d*)** | **MD (*d*)** |
|---|---|---|---|---|
| Working memory for numbers | 0.20 | .15 | −0.70 | −0.59 |
| Working memory for words | 2.67 | .10 | −1.18 | −0.58 |
| Digit span forward | 1.14 | .28 | −0.20 | −0.13 |
| Digit span backward | 0.31 | .57 | −0.28 | −0.09 |
| Rapid number naming | 0.83 | .36 | −0.22 | −0.03 |
| Rapid picture naming | 1.28 | .26 | −0.32 | −0.78 |
| Letter number sequence | 2.69 | .10 | 0.21 | −1.28 |
| Quantitative concepts | 0.45 | .50 | −0.83 | −0.50 |
| Block rotation | 0.43 | .51 | −0.63 | −0.29 |

Note: *d* is the standardized mean difference for the TA high to TA low and for the MD high to MD low. Negative *d* indicates that children with high reactivity obtained lower scores than children with low reactivity. MD = math disability; TA = typically achieving.

$^{*}p < .05$.