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Inhibition Performance in Children with Math Disabilities

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Inhibition Performance in Children with Math Disabilities

A Dissertation submitted in partial satisfaction
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in

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by

Kathryn Lileth Winegar

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Dedication

This work is dedicated to my daughter. May you always remain conscientious and a seeker of knowledge….

ABSTRACT OF THE DISSERTATION

Inhibition Performance in Children with Math Disabilities

by

Kathryn Lileth Winegar

Doctor of Philosophy, Graduate Program in Education
University of California, Riverside, June 2013
Dr. H. Lee Swanson, Chairperson

This study examined the inhibition deficit hypothesis in children with math disabilities (MD). Children with and without MD were compared on two inhibition tasks that included the random generation of numbers and letters. The results addressed three hypotheses. Weak support was found for the first hypothesis which stated difficulties related to inhibition are significantly related to math performance. I found partial support for this hypothesis in that inhibition was related to math problem solving, but not calculation. Further, only global measures of inhibition predicted math problem solving accuracy. Support was found for the second hypothesis which stated that performance for children with MD varies significantly from children without MD students on inhibition tasks. Deficits for children with MD were isolated to global performance on the random generation tasks. No support was found for the third hypothesis that inhibition deficits were isolated to number tasks among subgroups with math disabilities. The expected outcome for this study was that children identified with MD will exhibit greater inhibition difficulties than the non-MD group. This was obtained, however, it was specific to one inhibition measure, random letter generation, and solely to the math subgroup that showed more pervasive math deficits.

Keywords: executive functions, inhibition, random generation, math disabilities

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Inhibition Performance in Children with Math Disabilities

In the field of education most researchers agree that a critical subgroup related to learning disabilities is children who have serious problems with learning math concepts. The prevalence of students with a math disability (MD) has been estimated to fall between 5 and 8 percent (L. S. Fuchs, Compton, Fuchs, Paulsen, Bryant, & Hamlett, 2005; Geary, 2003; Gross-Tsur, Manor, & Shalev, 1996). However, the quantity of research focused on math difficulties is far less than the body of research focused on the characteristics of reading difficulties. This is thought to be partly due to the perception that it is socially more acceptable to have math difficulties than poor reading skills (O'Hare, Brown, & Aitken, 1991). Nonetheless, an increasing interest in problems with learning math concepts and subtypes of math disabilities has led to a need for studies focused on the underlying cognitive deficits related to MD. The results of numerous math studies from this expanding body of research emphasized the relationship between executive function (EF) abilities and math knowledge (Blair & Razzo, 2007; Bull, Johnston, & Roy, 1999; Mazzoco & Myers, 2003). It has been proposed that executive functions (EFs) consist of unitary and diverse cognitive processes and all EFs require the ability to inhibit irrelevant information to carry out tasks successfully (e.g., Miyake, Friedman, Emerson, Witzki, Mowerter, & Wager, 2000; Zhang & Wu, 2011). Research in the area of MD and EFs has specifically focused on performance on measures of inhibition and accurate math skills (e.g., Bull & Scerif, 2001; D'Amico & Guarnera, 2005; Passolunghi & Siegel, 2004). In an attempt to further the understanding of the MD-inhibition relationship, research has narrowed the focus to specific math domains (calculation versus word problems) and to specific types of inhibition stimuli including numerical versus non-numerical (e.g., Passolunghi & Pazzaglia, 2005; van der Sluis, de Jong, & van der Leij, 2004). The results of other studies have concluded that math achievement is not significantly related to EF abilities, more specifically the EF component of inhibition (e.g., Censabella & Noel, 2008; Willburger, Fussenegger, Moll, Wood, & Landerl, 2008). These studies reported that there are no significant differences between the inhibition abilities of children with or without MD. While a review of the literature indicates there is no consensus on the cognitive deficits underlying poor math achievement, recent research has suggested that executive functioning may be an important construct related to math difficulties (e.g., Blair & Razzo, 2007; Bull & Scerif, 2001; Passolunghi & Siegel, 2004). Furthermore, continued research in the area of math disabilities and related cognitive deficits has the potential for contributing to the development of diagnostic instruments for identification of math disabilities, as well as instructional strategies.

Literature Review

Cognitive Processes of Executive Functioning

Executive functions (EFs) have been classified as the control or self-regulatory operations that organize and direct cognitive functioning and behavioral activities. In daily problem-solving and decision-making, executive functioning includes the ability to be mentally and behaviorally flexible to changing conditions in order to respond in a coherent manner (Zelazo, Carter, Reznick, & Frye, 1997). A series of experiments completed by Baddeley, Emslie, Kolodny, and Duncan (1998) emphasized the need to view EFs as a multifaceted model of subsystems working together to control complex behavior. Furthermore, researchers have proposed that EF components are characterized by diverse aspects which develop at different rates and in some contexts the components work in unison (e.g., Miyake et al., 2000; Denckla, 2007). Broadly defined, all goal-directed behavior includes an EF component. Historically, executive functioning has been a familiar term to specialists in the medical field working with adults in the area of behavioral neurology and with researchers studying dementias (Denckla, 2007). Taken as a whole, EFs are best understood as functional networks that develop over time and are a resource for specific activities. Based on their cross-sectional study using multiple measures of EFs, Brocki & Bohlin (2004) concluded that they appear to develop across three stages: early childhood (6-8 years of age), middle childhood (9-12 years), followed by maturation during adolescence. Research completed by Anderson, Anderson, Northam, Jacobs, and Catroppa (2001) concluded that the rate of maturation of EFs during late childhood is reduced in comparison to the rapid development during early and middle childhood. Further study of the development of EFs by Huizinga, Dolan, and van der Molen (2006) supported a continuation of EF development into adolescence. Additionally, Huizinga et al. (2006) proposed that EF components develop at different rates, specifically that the ability to inhibit improves rapidly up to the age of 11 years while shifting skills reach maturation during adolescence, and general working memory skills continue to develop into young adulthood. Denkla (2007) further explained that EF components can be thought of as an interactive spiraling loop which supports the infrastructure for other cognitive systems, as well as an overseer of other cognitive domains. Thus, it has been proposed that EFs should be viewed as context- and situation-dependent self-regulatory processes (Bernstein & Waber, 2007).

Evidence for the proposal that the central executive consists of unitary and diverse EFs was supported through an investigation by Miyake et al. (2000). Based on confirmatory factor analysis Miyake et al. (2000) concluded that the cognitive processes falling under the umbrella of EFs include mental set shifting, information monitoring and updating, and inhibition of prepotent responses. Huizinga et al. (2006) also supported the importance of recognizing the unity and diversity of EF processes. It has been proposed that there is some unity across EF processes since all EFs require inhibitory processes (e.g., Miyake et al., 2000; Zhang & Wu, 2011). However, this finding has been inconclusive. For example, St Clair-Thompson and Gathercole (2006) identified updating and inhibition factors and provided no evidence for a shifting factor. Furthermore, it was concluded that the abilities to inhibit information and to update information in working memory were unrelated; providing support for findings that inhibition is dissociable from other EFs in children, as well as in adults. These outcomes were based on an exploratory factor analysis using a sample of 11 and 12 year old children. Overall, St Clair-Thompson and Gathercole (2006) concluded that inhibition was an important factor which supports general academic learning versus achievement in specific academic areas. In contrast, van der Sluis, de Jong, and van der Leij (2007) found distinct EF components for shifting and updating and presented no evidence for an inhibition factor. These results were based on a confirmatory factor analysis with a sample of typically developing 9 to 12-year-old students. It was proposed that inhibition may be more likely to distinguish between clinical and non-clinical samples versus being detectable in their sample of normally functioning children. van der Sluis et al. (2007) also concluded that it is difficult to measure inhibition and emphasized the underlying factor of task impurity. Task impurity may be contributing to the relationships between higher-order cognitive abilities, such as academic achievement, and executive functioning in that these relationships are at least partially due to non-executive processes. This complexity of the study of EFs was previously emphasized by Hughes and Graham (2002) in that performance on EF tasks may be impacted by other factors such as task familiarity or verbal demands. Thus, focus needs to be on the use of EF tasks that measure the ability to initiate and maintain adaptable goal-directed behaviors.

Inhibition Measures

Among the most frequently used tasks to measure cognitive processes of executive functioning within the framework of Baddeley’s (1986) model of working memory are random generation tasks (e.g., Baddeley et al., 1998; Miyake, Friedman, Rettinger, Shah,

& Hegarty, 2001; Towse & Neil, 1998). The random generation tasks are thought to measure EF capacities, specifically the component of inhibition, because participants are required to actively monitor candidate responses and suppress prepotent responses that would lead to well learned sequences, such as 1-2-3-4 or A-B-C-D (Towse & Neil, 1998). Baddeley proposed that random generation of letter or number sequences requires a high degree of executive functioning. Specifically, random generation requires the use of several executive cognitive processes including (a) holding the set size (e.g., numbers 1 to 10, letters A to Z), task related instructions, and an understanding of randomness in memory; (b) the integration and holding of this information in working memory; (c) avoiding interference and self-monitoring the response; and (d) making changes in response strategies in accordance with the concept of randomness (e.g., Jahanshahi, Saleem, Ho, Dirnberger, & Fuller, 2006; Peters, Giesbrecht, Jelicic, & Merckelbach, 2007). In sum, participants are required to create a retrieval strategy, to monitor the strategy for success, and to avoid repeating numbers or letters used before (Miyake et al., 2001). Random generation tasks have been chosen to measure abilities of the prefrontal cortex or executive functioning across a variety of research. Jahanshahi and Dirnberger (1999) used random generation tasks in their research that focused on the use of transcranial magnetic stimulation. They concluded that cognitive processes required during random generation tasks are attention-demanding. Miyake et al. (2000) proposed that random generation tasks required multiple executive functions; however, the component of inhibition was primarily used in order to suppress prepotent or well-learned responses. Specifically, the sources of distracting information are thought to be internal due to counting and alphabetical sequences having a higher degree of automaticity, and thus are much more easily activated than other sequences (Miyake et al., 2001).

A prominent set of random generation indices to quantify deviations from randomness were proposed by Ginsburg and Karpiuk (1994). Based on their analysis of these randomness indices, three factors were calculated that reflect the degree to which a response is random: seriation, repetition, and cycling. It was proposed that these factors tap different characteristics of randomness including inhibition of stereotyped cognitive schemas, response inhibition, and monitoring of previous output, respectively (e.g., Peters et al., 2007; Williams, Moss, Bradshaw, & Rinehart, 2002). More specifically, Williams et al. (2002) proposed that seriation includes random generation indices which tap an inability to suppress stereotypical schemas such as repeated patterns (e.g., 1-4,….1-4; A-D,…A-D) and consecutive digrams or ascending and descending counting sequences (e.g., 4-5; C-D). The seriation factor was shown to differentiate between a control group and disabled group, as well as to correlate positively with the neurocognitive *Stroop* task (Peters et al., 2007). *Stroop* tasks require participants to name the ink color of stimuli presented on cards when the ink color and printed word do not correspond such as the word GREEN printed in blue ink. Next, the repetition factor is observed when responses include the same number or letter being repeated in succession (e.g., 3-3; B-B). Excessive repetition is thought to reflect difficulties with suppression of a previous response or output inhibition (e.g., Peters et al., 2007; Williams et al., 2002). The repetition factor was shown to differentiate between disabled groups, in addition to a normal control group (Williams et al., 2002). The third factor, cycling, includes the number of repetitions of the same number or letter within a sequence (e.g., Williams et al., 2002; Peters et al., 2007). Williams et al. (2002) suggested that differences in cycling may be due to individual differences in cognitive abilities. Based on their findings, the nonrandom characteristic of cycling was observed more often by the disabled groups. Thus, the normal control group demonstrated a higher degree of random responses which is thought be related to greater cognitive abilities. Further investigation of the psychometric properties of random number generation (RNG) tasks by Peters et al. (2007) summarized that poor inhibition functions are reliably measured by RNG tasks. Their study supported criterion-related and construct validity of RNG tasks, specifically for parameters focused on seriation.

Additional research using random generation tasks to investigate characteristics of executive functioning supported both similarities and differences between random number and random letter generation tasks based on a sample of adults (Fisk & Sharp, 2004). The outcome of their study corroborated an inhibition component for number and letter tasks. Differences included number generation requiring updating ability (Miyake et al., 2000) while letter generation required the ability to efficiently access long-term memory (Fisk & Sharp, 2004). This difference is thought to be related to 10 versus 26 (numbers 1 to 10, letters A to Z) possible responses (e.g., Baddeley, 1996; Jahanshahi & Dirnberger, 1999; Fisk & Sharp, 2004). In summary, random generation tasks demand attention and poor performance reflects deficits in central executive or EF capacities.

A preferred random generation task design consists of a nonrandom (numbers/letters in order) trial as the control task followed by the random (numbers/letters out of order) trial (e.g., van der Sluis et al., 2004; Zhang & Wu, 2011). Administration of a nonrandom trial as the baseline followed by a random generation trial provides for a comparison score. The latter trial requires inhibition of an automatic response and replacement with a novel association (e.g., van der Sluis et al., 2004; Zhang & Wu, 2011). Thus, performance on the inhibition tasks can be compared with the performance on a control task which is similar in all aspects with the exception of the inhibition requirement. By analyzing contrasting performances on these pairs of tasks, the irrelevant but constant task requirements are reduced and the relevant differences from the EF component between the tasks can be the unit of analysis (e.g., van der Sluis et al., 2004; Zhang & Wu, 2011). This assists in addressing the problem of task impurity emphasized in previous research focused on measurement of the separate components of executive functioning one of which is inhibition (e.g., van der Sluis et al., 2007).

Executive Functioning and Math Achievement

When moving from the neuropsychological field to the field of educational psychology, the term executive functioning has been translated into terms that include planning, organization, self-monitoring, and general study skills. The literature has shown that executive processes likely contribute to acquisition of academic skills, including math knowledge (e.g., Blair & Razzo, 2007; Bull & Scerif, 2001; Passolunghi & Siegel, 2004). Specifically, poor executive functioning may be related to problems keeping track of the counting process and with sequencing the multiple steps during math procedures (Geary, 1993). More generally, Rourke and Conway (1997) concluded that there is a relationship between cognitive processes and procedures for calculation. Adults were described as relying on low order cognitive processes to execute previously learned math skills including the ability to retrieve information from semantic memory. In contrast, children rely on cognitive processes for acquiring math concepts and problem-solving strategies. Likewise, research has linked compromised cognitive processes of executive functioning to early acquisition of mathematics knowledge. Blair and Razzo (2007) reported that the performances on EF measures were primarily predictive of how children progressed in the area of mathematics. Thus, MD has been characterized as a disruption in acquisition of calculation skills and poor rate of learning problem-solving strategies. In addition, as Geary (1993) suggested, when math difficulties persist beyond second grade it is likely due to a math disability versus a developmental delay in math achievement. However, in contrast to reading skills, math skills are cumulative beyond the primary grades and math difficulties may manifest during different stages of a child's schooling. While there has been an increasing interest in problems with learning math concepts and subtypes of MD, no core set of underlying cognitive variables have been identified for MD (Mazzoco & Myers, 2003). Geary (2010) concluded that the most common characteristics of MD are difficulties with the procedural requirements of math problems, poor number sense, and problems with retrieval of math facts (fact retrieval deficit). More distinctively, some individuals store math facts as a visual representation while others may rely on a semantic memory system.

Children with comorbid reading and math problems may show slower number and word fact retrieval, while other children with math fact retrieval deficits do not have reading difficulties (Geary & Hoard, 2001; Geary, 2010). Furthermore, these retrieval deficits may be related to difficulties with inhibition of irrelevant information from entering working memory, a component of executive functioning. It has also been proposed that different cognitive processes support calculation versus word problem skills (L.S. Fuchs, Fuchs, Stuebing, Fletcher, Hamlet, Lambert, 2008; Rourke & Conway, 1997). Moreover, Fuchs et al. (2008) suggested that the cognitive impairments underlying word problem skills are more pervasive than the cognitive processes underlying calculation skills, possibly due to the requirement to construct a calculation problem to obtain information for successful problem solving. This is consistent with Mazzocco and Myers' (2003) proposal that poor executive functioning skills impact organization of math problems and the ability to apply strategies for successful math execution resulting in procedural errors. In sum, studies focusing on the relationship between cognitive deficits and math achievement have identified a relationship between executive functioning and a variety of math problems (e.g., Bull & Scerif, 2001; van der Sluis et al., 2004; Passolunghi & Siegel, 2004).

Further review of the literature indicated studies have linked the compromised cognitive processes of executive functions (EFs) to the procedural and retrieval difficulties seen in children with math difficulties. Lehto (1995) showed that mathematic achievement is more strongly related to executive functioning or the central executive versus the phonological loop, components of Baddeley's (1986) model of working memory. A study by Bull et al. (1999) supported the relationship between executive functioning and individual differences in math skills. It was found that children with lower math ability made a higher percentage of errors, even when reading and IQ were controlled for. Based on the use of a broad measure of executive functioning, the *Wisconsin Card Sorting Test*, Bull et al. (1999) emphasized that the primary conclusion to take from their study is that math achievement is related to poor executive functioning skills. Subsequent research focused on the relationship between math problems and subtypes or components of EFs. McLean and Hitch (1999) completed a study based on 8 and 9-year-old children and proposed that children with poor math skills show difficulties with the executive component of shifting in comparison to age-matched controls. Also, in comparison to ability-matched controls, children with MD performed lower on tasks requiring executive processes for controlling interactions with long term working memory. Additional research concluded that math requires the use of executive and phonological subsystems of working memory (Furst & Hitch, 2000). It was shown that the phonological loop (i.e., semantic short term memory) plays a major role for retaining temporary information during calculation tasks requiring fact retrieval, while executive functioning (i.e., inhibition of inappropriate representations) is required for math problem solving consisting of carrying operations and multiple steps. Thus, children's math skills will be related to their capacity to inhibit well-learned or routine operations that are incorrect for the specific problem. Bull and Scerif (2001) found that a major deficit of children identified as having poor math skills is their inability to use inhibition to suppress a learned strategy in order to switch to a new strategy. Their findings also support the notion of diversity and unity amongst EFs with some components of executive functioning operating well while other components may be deficient. More specifically, Bull and Scerif (2001) suggested that there is a domain-specific problem with inhibition of numerical stimuli based on their findings from the number-quantity *Stroop* task versus the color-word *Stroop* task. As explained by Blair, Knipe, and Gamson (2008), in the word version of the *Stroop* task, children are asked to name the ink color of the items when the ink color (i.e., red, blue, green, yellow) and printed word did not correspond (the word RED printed in green ink). For the number-quantity *Stroop* task, children are required to name the quantity of items (one, two, three, or four) when the quantity and printed number did not correspond (e.g., 222). Thus, the contradiction between the quantity signified by the number of items and the quantity presented by the printed number causes interference and may result in incorrect responses.

A study completed by van der Sluis et al. (2004) focused on the executive functions of inhibition and shifting in 10-year-old children with reading difficulties (i.e, word identification), math difficulties (i.e., calculation), and children with both reading and math difficulties. The results supported the view that children with reading difficulties, specifically word identification, do not show deficits in inhibition or shifting. As for children with poor calculation skills, the results showed that they exhibit deficits on tasks requiring both inhibition and shifting or a combination of EFs. This may be interpreted as a general inability to activate and coordinate different components of EFs simultaneously. Also in 2004, Swanson and Beebe-Frankenburger completed a study focusing on the relationship between working memory and mathematical problem-solving. Within their battery of cognitive processes, difficulties with inhibition were shown to be a characteristic of children at risk for serious math difficulties, specifically accuracy on word problems. Numerous studies completed by Passolunghi (e.g., D'Amico

& Passolunghi, 2009; Passolunghi, Cornoldi, & DeLiberto, 1999; Passolunghi & Pazzaglia, 2005; Passolunghi & Siegal, 2001; Passolunghi & Siegel, 2004) have also provided support for a relationship between inhibition abilities and children identified with MD. More recently, research completed by Peng, Congying, Beilei, and Sha (2012) concluded that children with MD show inhibition deficits on domain specific numerical tasks. In contrast, children with math and reading difficulties exhibited deficits on EF tasks consisting of verbal and numerical stimuli, as well as phonological storage deficits.

In general, the research summarized above provides support for an inhibition deficit hypothesis that proposes that MD is associated with poor inhibition. In contrast to this hypothesis, Censabella and Noel (2008) found no significant difference between MD and nonMD children's inhibition abilities based on performance in the domain-specific area of calculation skills. Censabella and Noel (2008) examined three specific functions of inhibition; suppression of irrelevant information, inhibition of prepotent responses, and interference control. Based on the performance of 10-year-old students, there were no significant differences between inhibition abilities of children with or without MD. They proposed that inhibition of irrelevant information might contribute to solving word problems; however, inhibition abilities are less important when solely completing calculation problems. Willburger et al. (2008) also concluded that EFs, specifically measures of inhibition and shifting, do not have a relevant influence on math or reading disabilities based on a sample of 8 to 10-year-old children. The children met criteria for their MD group if they performed poorly on a timed test of arithmetic skills focusing on number fact knowledge and simple calculations (addition, subtraction, multiplication, division). Similar to the Censabella and Noel (2008) study, Willburger et al. (2008) did not include math word problem solving skills as a component of their math disabled group.

More recent research has focused on the EF-MD relationship in samples of younger children (i.e., mean age of 6.5 years) using a variety of combinations of EF tasks and math proficiency (e.g., Lee, Ng, Pe, Ang, Hasshim, & Bull, 2012) or broad math composites (e.g., Toll, Van der Ven, Kroesbergen, & Van Luit, 2011; Van der Ven, Kroesbergen, Boom, & Leseman, 2012). The results of these studies indicated that performance on EF measures, including inhibition tasks, did not support the inhibition deficit hypothesis. However, it was proposed that due to math skills in early grades not requiring the use of multi-step strategies and processing of additional irrelevant information the requirement for inhibition is reduced (Toll et al., 2011).

In sum, different aspects of math achievement are more likely to be related to inhibition abilities than others and the inhibition-MD relationship varies depending on age or maturation of EF components (Mazzocco & Kover, 2007). It is important for the field of education to recognize that EFs have diverse aspects that develop at different rates in order to establish differentiated student profiles and more effective interventions (Fischer & Daley, 2007). A broader understanding of the developmental patterns of EFs and their relationship to learning disabilities, such as math skills, could impact choices of teaching materials and intervention strategies (Bull & Scerif, 2001; Rourke & Conway, 1997). While support for a relationship between EFs and math achievement is growing, inconsistencies in the literature indicate the need for additional research to further investigate the complexities of EFs and individual differences in math skills.

Summary and Statement of Purpose

The main goal of this study was to further examine the relationship between inhibition and math achievement. Specifically, this study examined the relationship between math skills and inhibition. Measures of inhibition relied on performance related to random generation tasks because they have been shown to provide valid assessments of inhibition abilities (e.g., Miyake et al., 2000; Peters et al., 2007). The present study investigated the relationship between domain-specific math measures (calculation, word problems) and domain-specific inhibition tasks (e.g., random number generation, random letter generation). Three research questions directed this study:

1) Does a significant relationship exist between inhibition and math performance, and if so does the relationship occur on both math problem solving and calculation measures?
2) Does the performance on inhibition tasks of students with MD differ significantly from students without MD?
3) Does inhibition performance of students with MD reflect a domain-specific or domain general deficit?

Methods

Participants

One hundred twenty-six (126) children from grades 3 and 4 participated in this study. These 126 students were obtained from a larger sample of 315 students from grades 2 to 4 in two Southern California school districts. Parent consent was obtained for all children prior to the commencement of the study. The total sample included 10 students identified as English Language Learner's (ELLs) all of whom scored 3 or above on the California Language Development Test (CELDT) and were determined by the school district to have adequate reading skills in English. All of the students interacted with their peers in their homerooms on tasks and activities related to the district wide academic curriculum. The school wide math instruction was the *enVisionMATH* Learning Curriculum (Pearson Publishers, 2009). These children were tested on measures of fluid intelligence, reading ability, and math ability. All children included in the present study performed within the average range on measures of fluid intelligence and word recognition skills. Also for the present study children in grade 2 were eliminated to reduce possibility of developmental delay in math achievement. Based on the operational criteria listed below, ninety six (96) children were identified as at risk for math disabilities (MD) and 30 children were identified as not at risk for MD. From the final sample of 126 children, three subgroups of children with MD were established: children with low calculation-low word problem solving skills, children with average calculation-low word problem solving skills, and children with average calculation-low word problem solving-low reading comprehension skills. These children were compared to a control group with average calculation and average word problem skills. The groups were matched as closely as possible by the proportion of representation by gender, grade, and ethnicity.

The rationale for this subgrouping was based on previous findings in the literature (Mazzocco & Kover, 2007), in that different aspects of math may be more associated with EFs than others. Moreover, studies have shown that the processes that underlie calculation difficulties are not the same as those that underlie problem solving difficulties (e.g., Fuchs et al., 2005, 2008). Specifically, research has suggested that language and reading deficits play critical roles in problem solving skills, attention problems and poor processing speed impact calculation skills, while components of working memory play a role in both calculation and problem solving skills (Fuchs et al., 2008). The literature has called attention to the fact that unlike calculation problems, math word problems are a form of text which require decoding and comprehension skills (Swanson & Sachse-Lee, 2001). In addition, it has been found that reading comprehension is a more potent predictor of problem solving than calculation (e.g., Swanson, Cooney, Brock, 1993) and therefore it is necessary to take into consideration reading comprehension proficiency in the analyses. Thus, three subgroups were created among children with MD based on normed scores above or below the 25^{th} percentile on measures of calculation, word problem solving and reading comprehension.

Of the 96 children identified with MD, 31 children (16 girls and 15 boys) yielded low calculation, word problem solving and reading comprehension performance, 25 children (11 girls and 14 boys) yielded average calculation performance, but low word problem solving and reading comprehension performance, 40 children (19 girls and 21 boys) yielded average calculation and reading comprehension performance, but low word problem solving performance. In addition, 30 children (13 girls and 17 boys) participated as chronological age matched controls. The distribution of the gender by subgroup was statistically non-significant, χ^2 (3, *N*=126) = .52, $p > .05$ as was the distribution of grades 3 and 4 over groups, χ^2 (3, *N*=126) = 3.82, $p > .05$, and ethnicity χ^2 (12, *N*=126) = 7.15, $p > .05$. Ethnic representation of the sample included Anglo (56.8%), Hispanic (14.4%), African American (8.0%), Asian (4.8%(, and mixed and/or other (16.0 %; e.g., Anglo and Hispanic, Native American). The mean socioeconomic status (SES) of the sample consisted of low SES to middle SES based on free lunch participation, parent education or occupation.

Definition of Math Disabilities (MD)

This study used a cut-off score criterion on standardized math achievement tests to determine identification of MD. There is consensus among some researchers that it is more appropriate to use a fixed criterion for MD (below a cutoff score on academic measures of math skills) rather than a discrepancy between academic achievement and intellectual ability. More specifically, the 25th percentile cut-off score on standardized achievement measures has been commonly used to identify children at risk for learning disabilities (e.g., Fletcher, Epsy, Francis, Davidson, Rourke, & Shaywitz, 1989; Siegel & Ryan, 1989). This study used the operational criteria for defining MD as scores below the 25th percentile (below a standard score of 90 or scale score of 8) on a norm-referenced calculation math test; the Numerical Operations subtest from the *Wechsler Individual*

Achievement Test (*WIAT*; Psychological Corporation, 1992), and/or scores below the 25th percentile a norm-referenced word problem solving math test; the Story Problem subtest from the *Test of Math Ability* (*TOMA-2*; Brown, Cronin, & McEntire, 1994). In order to reduce other pre-existing factors (e.g., low cognitive functioning, poor reading skills) additional cut-off criteria defining MD in the present study included performance above the 25th threshold on measures of fluid intelligence (*Colored Progressive Matrices Test*; Raven, 1976) and the Word Identification subtest from the *Wide Range Achievement Test* (*WRAT-III*; Wilkinson, 1993).

It is important to note that extreme groups (removing children close to the cut-off scores in the comparisons) were not created. Of the 25 children with average calculation performance, but low word problem solving and reading comprehension performance, 14 were close to the arbitrary subgroup criteria for low reading comprehension and 7 were close for low word problem solving. Of the 40 children with average calculation and reading comprehension performance, but low word problem solving performance, 15 were close to the cut-off score for average reading comprehension and 11 for low word problem solving. However, the 31 children with low calculation, word problem solving and reading comprehension performance showed an even distribution on all three academic measures. The removal of children to create extreme groups has come under criticism because it creates several artifacts and unwarranted assumptions about linearity, group membership, and the reliability of the findings are more likely to be reduced rather than increased related to these procedures (Preacher, Rucker, MacCallum, & Nicewander, 2005).

Classification Measures

Fluid intelligence. To determine if all children included in this study could be classified as being within the normal range on a measure of fluid intelligence, the *Colored Progressive Matrices* (Raven, 1976) was administered. Children were given a booklet with patterns displayed on each page and with each pattern revealing a missing piece. For each pattern, six possible replacement pattern pieces were displayed. Children were required to circle the replacement piece that best completed the patterns. After the introduction of the first matrix, children completed their booklets at their own pace. Patterns progressively increased in difficulty. The *Colored Progressive Matrices* has been shown to correlate significantly (r = .70) with the Performance scale of the *Wechsler Intelligence Scale for Children* (Raven, 1976). The overall score (range 0 to 36) was the number of problems solved correctly, which yielded a standardized percentile score.

Word recognition. Word recognition was assessed by the decoding subtest of the *Wide Range Achievement Test* (*WRAT-III*; Wilkinson, 1993). The *WRAT-III* decoding task provided a list of words of increasing difficulty that are presented out of context. The children were required to read the words until ten errors occurred. The raw score was the number of words read correctly with raw score range of 15 to 57 (each child was awarded 15 points at start to their raw score per the manual), which yielded a standardized score (M=100, SD=15). Norms for the *WRAT-III* were derived based on a sample of 4,433 individuals, ages 5-75, across the United States. The median test coefficient alphas for the *WRAT-III* subtests ranged from .88 to .95 and test-retest coefficients ranged from .91 to

.98. The *WRAT-III* has been shown to correlate significantly (r = .87) with the Total Reading composite of the *Standford Achievement Test* (Wilkinson, 1993).

Reading comprehension. Reading comprehension was assessed by the Text Comprehension subtest from the *Test of Reading Comprehension* (*TORC-3*, Brown, Hammill, & Weiderholt, 1995). The purpose of this task was to assess the child's text comprehension of topic or subject meaning during reading activities. Comprehension questions were drawn from the reading of short-paragraphs. For each item the student was instructed to first read silently the five questions, to next read the paragraph, then answer the five questions (each with four possible multiple choice answers). The final score was the number of questions answered correctly (raw scores ranged from 0 to 60), which yielded a standardized scaled score (*M*=10, *SD*=3). The *TORC-3* has been shown to correlate significantly (r = .64) with the broad reading cluster of the *Woodcock-Johnson III Tests of Achievement* (Brown et al., 1995). The *TORC-3* was normed on 950 students in grades 2-12 across 19 states in the United States. The coefficient alphas for the *TORC-3* subtests are reported at .90 and above as calculated across ages and test-retest reliability ranged from .79 to .88.

Word problems. The *Test of Mathematical Ability, Second Edition* (*TOMA-2*; Brown et al., 1994) was developed for use in grades 3 to 12. The word problem subtests from the *TOMA-2* were administered to assess word problem solving skills. The students were required to silently read short story problems that include computational questions and then work out the answers in the provided space. As stated above, to reduce influence of poor reading skills children who scored below the 25^{th} threshold on the Word

Identification subtest from the *Wide Range Achievement Test* (*WRAT-III*; Wilkinson, 1993) were eliminated from the study. The *TOMA-2* standardization sample is comprised of 2,147 individuals from 26 states across the United States. The raw score for the word problem math subtest ranged from 0 to 25, which yielded a standardized scale score (*M*=10, *SD*=3). The reliability coefficients for the *TOMA-2* subtests are above .80. The *TOMA-2* has been shown to correlate significantly (r = .51) with the *Key Math Diagnostic Arithmetic Test* (Brown et al., 1994).

Arithmetic calculation. The Numerical Operations subtest from the *Wechsler Individual Achievement Test* (WIAT; The Psychological Corporation, 1992) was administered. This subtest required the student to perform written computation to number problems that increased in difficulty. Problems begin with simple single digit calculations (2+2=) and continued up to algebra. The final score was the number of problems correct (raw score range was 0 to 40), which yielded a standard score (*M*=100, *SD*=15). The reliability coefficients for the *WIAT* subtest range from .82 to .91 by age and test-retest coefficients ranged from .85 to .98 on the subtests. The *WIAT* Numerical Operations subtest has been shown to correlate significantly (r = .81) with the Computation subtest of the *Kaufman Test of Educational Achievement* (The Psychological Corporation, 1992).

Inhibition Measures

Random generation tasks. The random generation tasks have been well articulated in the literature (e.g. Towse & Cheshire, 2007). The task is assumed to measure inhibition because participants are required to actively monitor candidate responses and suppress responses that would lead to well learned sequences, such as 1-2-

3-4 or A-B-C-D (Towse & Neil, 1998). Each child was asked to write as quickly as possible numbers first in sequential order or letters in alphabetical order to establish a baseline. Children were then asked to quickly write numbers or letters in a random non-systematic order.

For example, for the number section, students were first asked to write numbers from 1 to 10 in order (i.e., 1-2-3-4) as quickly as possible in a 30-second period (nonrandom number generation or nRNG). Students were then asked to write numbers as quickly as possible "out of order" (i.e., 3-9-4-7) within a 30-second period. Children were not explicitly taught the definition of random generation. Rather, the children were instructed to "Now I want you to write numbers between 1 and 10 but this time out of order, like 1, 5, 2, 8 over and over. Don't forget to randomly use all the numbers between 1 and 10." Similarly, for the letter generation tasks, students were first asked to write letters in alphabetical order (i.e., A-B-C-D) as quickly as possible in a 30-second period (nonrandom letter generation or nRLG). Students were then asked to write letters as quickly as possible "out of order" (i.e., D-L-G-A) within a 30-second period. No children asked for a definition of random. For an example of the administration instructions for the inhibition measures see Appendix A.

A difference score was obtained based on the number of digits or letters in the nonrandom tasks minus the number of digits or letters in the random task without consideration of errors. This solely represented the reduction in number of responses when the inhibition component was added. For the random number and letter generation tasks an overall randomness score was obtained to represent a global measure of inhibition in that only numbers or letters produced in random order were counted (RNG, RLG). Additional randomness indices consisted of measuring specific inhibition errors that included identical pairs or the tendency to produce repeated responses (Repetition), tendency to repeat the same number or letter within a series (Redundancy), production of consecutive digrams in steps of 1 and steps of 2 (Series1, Series2), production of repeated patterns (RepeatPattern), starting with the beginning or ending of the number or letter sequence and last, the inability to suppress stereotypical schemas. A stereotypical error index unique to the number task included producing the number 0 or numbers greater than 10. Likewise, an error index unique to the letter task was stereotypical schemas such as acronyms or words (e.g., N-B-C or T-O-P). For a complete description of the inhibition randomness indices for random number generation see Appendix B and for random letter generation see Appendix C.

Procedures

All measures were administered by trained doctoral students at the children's school site and during school hours. The children were tested in both small group and individually in either an empty classroom (for group administration) or a quiet room (i.e., the school library) for individual administration. The *Raven* (Raven, 1976), *WIAT* (Psychological Corporation, 1992), random number generation, and random letter generation tasks were group administered on Day 1 during a 60-minute session. The *TOMA-2* (Brown et al., 1994) and *TORC-3* (Brown et al., 1995) were group administered on Day 2 during another 60-minute session. The *WRAT-III* (Wilkinson, 1993) was individually administered on Day 3 during the last 60-minute session. Test administration was completed on consecutive days and the order of test administration was randomized to prevent order effect.

Results

In light of the inconsistencies in the literature on the relationship between inhibition and math skills, three hypotheses were tested: 1) difficulties related to inhibition are significantly related to math performance, 2) children with MD vary significantly from children without MD on inhibition tasks, and 3) inhibition difficulties in children with MD are domain specific (inhibition difficulties are more likely to occur on number than letter tasks).

The results are organized within two subsections. In the first section, I presented the results on the total sample. In the second section, I attended to the results on the subgroup comparisons.

Total Sample

The purpose of this first analysis was to determine if inhibition performance in the total sample predicted calculation and word problem solving performance. Descriptive statistics for the classification, control tasks, and inhibition measures are provided in Table 1. The correlation matrix (N=126) including the various inhibition randomness indices are presented in Table 2.

Exploratory factor analysis. As shown in Table 2, several of the randomness indices were significantly correlated with one another. (Note - N before an index refers to number generation, e.g., NRepetition, and L before an index refers to letter generation, e.g, LRepetition). For example, correlations between random letter

Table 1. Means and Standard Deviations of Classification Control Tasks and Inhibition Indices for Total Sample

Variable	N	Mean	Std. Deviation
		Classification	
Raven (percentile)	126	0.64	0.21
WRAT (standard score)	126	107.51	10.61
TORC (scaled score)	125	10.11	2.19
WIAT (standard score)	126	96.13	17.54
TOMA (scaled score)	120	7.78	2.35
		Control tasks	
nRNG (raw score)	126	33.41	8.61
nRLG (raw score)	126	21.60	8.13
		Inhibition indices	
RNG	126	6.70	3.87
RLG	126	8.06	3.22
NDifference	126	21.67	8.92
NSeries1	126	3.75	6.66
NSeries2	126	7.04	12.09
NRepetition	126	0.13	0.46
NRedundancy	126	0.46	0.93
NRepeated Pattern	126	1.25	3.09
NError	126	0.12	0.39
NStart	126	0.55	0.50
LDifference	126	9.86	8.81
LSeries1	126	4.38	4.45
LSeries2	126	1.52	1.75
LRepetition	126	0.13	0.89
LRedundancy	126	0.45	1.32
LRepeated Pattern	126	0.14	0.87
Linguistic	126	0.49	0.76
LStart	126	0.46	0.91

Note. *Raven = Raven Colored Progressive Matrices*. *WRAT = Wide Range Achievement Test Word Recognition*. *TORC = Test of Reading Comprehension*. *WIAT = Wechsler Individual Achievement Test Numerical Operations*. *TOMA = Test of Mathematical Ability Word Problems*. nRNG = in order number generation. nRLG = in order letter generation. For the inhibition indices N = number and L = letter; all raw scores. RNG = global random number generation. RLG = global random letter generation. Difference = in order minus out of order. Series1 = ascending/descending series in steps of 1 (1-2-3 or 3-2-1; A-B-C or C-B-A). Series2 = ascending or descending series in steps of 2 (2-4-6 or 6-4-2; A-C-E or E-C-A). Repetition = repeat numbers/letters (4-4, C-C). Redundancy = repeat number/letter within series of 10. Repeat Pattern = digram repetitions (A-D…A-D, 2-5…2-5). Start = begin with numbers 1 or 10/letters A or Z. NError = include 0 or number greater than 10. Linguistic = acronyms or words.

Table 2. Intercorrelations Among Inhibition Randomness Indices

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.	17.	18.
1. RNG	--	**.39***	-.04	.01	-.18	-.04	.23	.16	.06	.09	.02	.21	.01	.004	-.03	-.03	-.12	-.07
2. RLG		--	.17	-.15	-.17	-.20	.18	-.03	.06	.05	-.11	-.12	-.04	.21	.21	.10	-.05	-.03
3. NDifference			--	**-.37***	-.14	-.13	-.15	-.32	.02	.06	.13	-.12	-.03	.10	.02	.05	.10	.00
4. NSeries1				--	-.13	.05	.09	**.39***	.00	-.04	-.07	**.47***	.02	-.04	-.07	-.05	-.01	.09
5. NSeries2					--	-.03	-.03	**.37***	-.11	-.18	-.04	.04	.19	-.06	.14	.12	.16	.06
6. NRepetition						--	.13	-.07	-.05	.06	-.08	-.06	.14	-.04	-.02	-.03	-.05	.06
7. NRedundancy							--	.05	.16	-.05	-.06	.04	.05	.15	.14	.13	-.01	.09
8. NRepeatPattern								--	-.03	.01	.23	.24	.10	-.06	.02	.04	.16	-.06
9. NError									--	-.05	-.10	-.01	-.07	-.04	-.06	-.05	-.12	-.02
10. NStart										--	.14	-.03	-.07	-.14	-.14	-.02	-.02	-.01
11. LDifference											--	.02	-.16	-.04	-.15	-.05	-.04	-.01
12. LSeries1												--	.13	-.09	-.14	-.09	-.10	.02
13. LSeries2													--	-.07	.02	.03	.01	.09
14. LRepetition														--	**.71***	**.91***	.05	**.77***
15. LRedundancy															--	**.80***	.14	**.51***
16. LRepeatPattern																--	.11	**.80***
17. Linguistic																	--	.03
18. LStart																		--

Note. RNG = global random number generation. RLG = global random letter generation. For the inhibition indices N = number and L = letter. Difference = numbers/letters in order minus numbers/letters out of order. Series1 = ascending/descending series in steps of 1 (1-2-3 or 3-2-1; A-B-C or C-B-A). Series2 = ascending or descending series in steps of 2 (2-4-6 or 6-4-2; A-C-E or E-C-A).Repetition = repeat numbers/letters (4-4, C-C). Redundancy = repeat number/letter within series of 10. Repeat Pattern = digram repetitions (A-D…A-D; 2-5…2-5). Start = begin with numbers 1 or 10 and letters A or Z. NError = include 0 or number greater than 10. Linguistic = acronyms or words. Significant correlations are shown in **bold**. *$p < .0001$.

generation indices LRepetition and LRepeatPattern was r = .91 and between LRepeatPattern and LStart was r = .80. Thus, for data reduction purposes, it was necessary to combine those variables that shared variance, via an exploratory principal component analysis. An exploratory analysis was computed rather than a confirmatory analysis since I had no a priori sense of how the randomness indices would cluster. All assumptions for the factor analysis were met. That is, the variables demonstrated acceptable normal distributions. Four students were identified as being outlying cases (randomness scores greater than 3 standard deviations from the mean) and were deleted. One of these students met criteria for group 3 (children with MD who performed below the 25^{th} percentile on word problems, but above the 25^{th} percentile on calculation and reading comprehension measures), and the remaining three met criteria for the control group. Next, in order to explore relations between the types of inhibition errors, scores on the randomness indices were entered into a principal components analysis with varimax rotation. Factors with eigenvalues greater than 1 were retained. The factor loading scores for this analysis are shown in Table 3.

Seven factors were identified, accounting for 68.5% of the variance in total. Factor loadings of .45 and above were used to guide interpretation of factor structure. Scoring indices for four random letter generation tasks (LRepetition, LRedundancy, LRepeatPattern, LStart) loaded highly on Factor 1 (named Letter Patterns). Letter Patterns represented a tendency to rely on a pattern for letter generation such as repetition of letters consecutively or frequently within a short sequence or to produce digram patterns (e.g., D-X-V-**Z-Q**-C-G-O-**Z-Q**-T-S).

Table 3. Factor Loadings for the Principal Components Analysis with Varimax Rotation

	Factor						
Inhibition Indices	1	2	3	4	5	6	7
RNG	-0.06	0.18	**0.80**	-0.10	0.03	0.14	0.08
RLG	0.12	-0.22	**0.78**	-0.06	-0.17	-0.07	-0.05
NDifference	0.07	-0.45	0.06	-0.23	-0.55	0.14	0.15
NSeries1	0.02	**0.85**	-0.09	-0.06	0.16	-0.04	-0.09
NSeries2	0.01	-0.003	-0.15	**0.76**	0.44	-0.17	0.25
NRepetition	0.002	-0.10	-0.21	-0.19	**0.74**	0.12	0.28
NRedundancy	0.14	0.05	**0.48**	0.03	**0.54**	-0.14	-0.12
NRepeatPattern	-0.02	**0.53**	0.18	**0.65**	0.09	0.21	-0.05
NError	-0.09	0.02	0.16	-0.18	0.10	-0.41	-0.45
NStart	-0.11	-0.09	0.12	-0.19	0.15	**0.67**	0.04
LDifference	-0.04	0.07	-0.05	0.14	-0.17	**0.70**	-0.23
LSeries1	-0.06	**0.78**	0.09	-0.13	-0.19	-0.01	0.26
LSeries2	-0.01	0.08	0.07	0.10	0.11	-0.19	**0.81**
LRepetition	**0.95**	-0.05	0.09	-0.06	-0.05	-0.02	-0.07
LRedundancy	**0.81**	-0.13	0.12	0.20	0.03	-0.15	0.00
LRepeatPattern	**0.97**	-0.03	0.03	0.10	-0.01	-0.05	0.01
Linguistic	0.09	-0.17	-0.07	**0.53**	-0.06	0.05	-0.01
LStart	**0.87**	0.12	-0.12	-0.07	0.06	0.07	0.10

Note. Factor loadings greater than .45 were considered meaningful for factor interpretation. RNG = global random number generation (numbers written in random order). RLG = global random letter generation (letters written in random order). For the inhibition indices N = number and L = letter. Difference = in order minus out of order. Series1 = ascending/descending series in steps of 1 (1-2-3 or 3-2-1; A-B-C or C-B-A). Series2 = ascending or descending series in steps of 2 (2-4-6 or 6-4-2; A-C-E or E-C-A). Repetition = repeat numbers/letters (4-4, C-C). Redundancy = repeat number/letter within series of 10. Repeat Pattern = digram repetitions (A-D…A-D, 2-5…2-5). Start = begin with numbers 1 or 10/letters A or Z. NError = include 0 or number greater than 10. Linguistic = acronyms or words.

Factor 2 (named Number Letter In Order) yielded high loadings for indices measuring the tendency to produce number and letter generation in ascending or descending order in steps of 1 (e.g., 8-7-6-5; L-M-N-O) for both the random number and letter generation tasks (NSeries1, LSeries1). Factor 3 (named Global Inhibition) loadings were high for the global random number and letter generation indices (RNG, RLG). Global Inhibition represented general inhibitory skills in that only numbers and letters written in random order were counted. Factor loadings for two number indices (NSeries2, NRepeatPattern) clustered on the Factor 4 (named Number Patterns). Number Patterns represented the tendency to produce numbers in ascending or descending order in steps of 2 (e.g., 2-4-6-8) or to produce digram patters (e.g., **4-8**-1-6-2-9-**4-8**). Factor 5 (named Number Duplication) yielded high loadings for two number indices, NRepetition and NRedundancy. Number Duplication represented a tendency to produce repeated digits consecutively or frequently within a sequence. LDifference and NStart produced shared variance which resulted in high loadings on Factor 6 (named Letter Number Errors). Factor 7 (named Letters In Order) consisted of a high loading for one random letter generation index measuring the tendency to alphabetize in ascending or descending series in steps of 2, for example (A-C-E-G). Overall, the factor analysis showed that the individual scoring indices measured different constructs.

Regression analyses. Next, composite scores were created by taking the mean z-score for those variables that loaded highly on each factor. These composite scores were subsequently entered into simultaneous-entry multiple regression analyses in order to predict calculation and problem solving performance. This simultaneous entry was completed to determine those components that contributed unique variance (variance that partials out the contribution of the remaining composite scores). Prior to analysis, all assumptions regarding outliers, normality, and colinearity were met. Results of the multiple regression analyses are presented in Table 4 and Table 5.

As shown for math calculation in Table 4, the complete regression model was not significant, F (7, 125) = .99, p = .44. In addition, none of the individual factors significantly predicted accuracy of calculation skills. These results are in contrast to prediction of word problem solving accuracy shown in Table 5. Although the regression equation did not reach an overall level of significance for word problem skills, F (7, 119) = 1.97, p = .07, accuracy of word problem skills was predicted by Factor 3 (p = .001). Factor 3 consisted of high loadings for global random number and letter generation accuracy (i.e., RNG, RLG). The composite scores for the remaining six factors were not significantly associated with calculation or word problem skills.

In summary, these analyses addressed the first question as to whether difficulties related to inhibition were significantly related to math performance. Partial support was found for this hypothesis. The results indicated that overall random generation was related to math word problem solving, but not to calculation skills.

Subgroup Comparisons

Overall, the results showed that only the global measures of random generation predicted math performance and these results were isolated to word problem solving accuracy. Thus, it was of interest to determine whether additional fine grain

Table 4. Simultaneous Entry Regression Analysis for Factors Predicting Calculation (N=126)

Factor	*B*	SE B	β
1. Letter Patterns	-.38	.27	-.13
2. Number Letter In Order	-.47	.36	-.13
3. Global Inhibition	.66	.37	.18
4. Number Patterns	.60	.37	.16
5. Number Duplication	-.24	.34	-.07
6. Letter Number Errors	-.13	.33	-.04
7. Letters In Order	-.06	.22	-.03

Note. Letter Patterns = LRepetition, LRedundancy, LRepeatPattern and LStart. Number Letter In Order = NSeries1 and LSeries1. Global Inhibition = RNG and RLG. Number Patterns = NSeries2 and NRepeatPattern. Number Duplication = NRepetition and NRedundancy. Letter Number Errors = LDifference and NStart. Letters In Order = LSeries2. RNG = global random number generation. RLG = global random letter generation. For the inhibition indices N = number and L = letter. Difference = in order minus out of order. Series1 = ascending/descending series in steps of 1 (1-2-3 or 3-2-1; A-B-C or C-B-A). Series2 = ascending or descending series in steps of 2 (2-4-6 or 6-4-2; A-C-E or E-C-A). Repetition = repeat numbers/letters (4-4, C-C). Redundancy = repeat number/letter within series of 10. Repeat Pattern = digram repetitions (A-D…A-D, 2-5…2-5). Start = numbers 1 or 10/letters A or Z

Table 5. Simultaneous Entry Regression Analysis for Factors Predicting Word Problems (N=120)

Factor	B	SE B	β
1. Letter Patterns	.12	.26	.04
2. Number Letter In Order	-.41	.35	-.11
3. Global Inhibition	1.17	.36	.33*
4. Number Patterns	.55	.37	.15
5. Number Duplication	-.30	.33	-.09
6. Letter Number Errors	.05	.32	.02
7. Letters In Order	-.16	.22	-.07

Note. Letter Patterns = LRepetition, LRedundancy, LRepeatPattern and LStart. Number Letter In Order = NSeries1 and LSeries1. Global Inhibition = RNG and RLG. Number Patterns = NSeries2 and NRepeatPattern. Number Duplication = NRepetition and NRedundancy. Letter Number Errors = LDifference and NStart. Letters In Order = LSeries2. RNG = global random number generation. RLG = global random letter generation. For the inhibition indices N = number and L = letter. Difference = in order minus out of order. Series1 = ascending/descending series in steps of 1 (1-2-3 or 3-2-1; A-B-C or C-B-A). Series2 = ascending or descending series in steps of 2 (2-4-6 or 6-4-2; A-C-E or E-C-A). Repetition = repeat numbers/letters (4-4, C-C). Redundancy = repeat number/letter within series of 10. Repeat Pattern = digram repetitions (A-D…A-D, 2-5…2-5). Start = begin with numbers 1 or 10/letters A or Z.
* p <.001.

analyses that separated the sample into various subgroups could more precisely examine the contribution of inhibition to math performance.

Multivariate analysis of variance (MANOVA). Shown in Table 6 are the means and standard deviations presented by the four groups for all reading comprehension, math and inhibition measures. Moreover, Table 6 displays the characteristics of the three MD subgroups in comparison to the control group. Group 1 included children who performed below the 25th percentile on calculation and word problem measures; group 2 included children who performed above the 25th percentile on calculation, but below the 25th percentile on word problem and reading comprehension measures; and group 3 included children who performed below the 25th percentile on word problems, but above the 25th percentile on calculation and reading comprehension measures. The control group included children who performed above the 25th percentile on calculation, word problem solving, and reading comprehension classification measures.

Nonrandom and random generation. The first analysis compared the four groups on the nonrandom generation tasks. That is, before comparisons could be made on inhibition measures (those derived from the random aspect of the task) it was necessary to determine if fundamental differences occurred when required to produce information in order. The next analysis considered the number of items that were produced as a function of the random aspect yet without consideration of randomness errors. This merely reflects the reduction in quantity of numbers or letters produced when the inhibition component was added.

Table 6. Means and Standard Deviations For Independent and Dependent Variables by Group

	Group 1		Group 2		Group 3		Group 4	
	Low Calculations Low Word Problems		Average Calculation Low Word/Read Comp		Average Calculation Low Word Problems		Control	
	(n=31)		(n=25)		(n=40)		(n=30)	
Variable	M	SD	M	SD	M	SD	M	SD
TORC (scaled score)	8.84	2.16	8.04	1.49	11.03	1.07	11.87	1.66
WIAT (standard score)	69.45	9.85	104.4	8.52	103.33	6.35	107.23	9.60
TOMA (scaled score)	6.23	0.96	6.74	1.05	6.75	1.03	11.40	1.16
nRNG	30.19	11.76	34.80	6.87	34.33	7.47	34.37	6.88
RNG	5.61	3.32	6.02	3.59	6.85	3.53	8.03	4.72
nRLG	21.35	9.80	21.04	6.11	21.03	9.36	23.07	5.81
RLG	6.94	3.09	7.56	3.19	8.05	2.75	9.67	3.47
NDifference	19.61	12.27	24.04	7.89	21.68	7.40	21.83	7.28
NSeries1	4.65	11.36	2.96	3.91	4.28	5.06	2.77	2.80
NSeries2	6.32	11.79	5.02	9.00	7.33	13.02	8.93	13.54
NRepetition	0.23	0.76	0.08	0.28	0.13	0.33	0.10	0.31
NRedundancy	0.52	0.96	0.44	1.12	0.4	0.87	0.50	0.82
NRepeatPattern	0.71	2.21	0.76	2.11	1.83	4.26	1.43	2.66
NError	0.10	0.40	0.12	0.44	0.15	0.36	0.10	0.40
NStart	0.52	0.51	0.60	0.50	0.53	0.51	0.57	0.05
LDifference	9.84	8.15	9.24	5.33	10.18	12.65	9.97	5.16
LSeries1	4.32	4.92	4.48	3.92	5.02	5.27	3.27	2.88
LSeries2	1.03	1.03	2.80	2.77	1.33	1.16	1.20	1.21
LRepetition	0.06	0.25	0.00	0.00	0.00	0.00	0.47	1.78
LRedundancy	0.71	1.55	0.12	0.44	0.30	0.76	0.67	1.95
LRepeatPattern	0.16	0.58	0.04	0.2	0.03	0.16	0.37	1.67
Linguistic	0.45	0.62	0.64	0.76	0.48	0.91	0.43	0.68
LStart	0.35	0.49	0.44	0.51	0.40	0.50	0.67	1.65

Note. Raw scores unless otherwise specified. *TORC = Test of Reading Comprehension. WIAT = Wechsler Individual Achievement Test Numerical Operations. TOMA = Test of Mathematical Ability Word Problems.* nRNG Order = nonrandom number generation. RNG = global random number generation. nRLG = nonrandom letter generation. RLG = global random letter generation. For the inhibition indices N = number and L = letter. Difference = numbers/letters in order minus numbers/letters out of order. Series1 = ascending/descending series in steps of 1 (1-2-3 or 3-2-1; A-B-C or C-B-A). Series2 = ascending or descending series in steps of 2 (2-4-6 or 6-4-2, A-C-E or E-C-A). Repetition = repeat numbers/letters (4-4, C-C). Redundancy = repeat number/letter within series of 10. Repeat Pattern = digram repetitions (A-D…A-D, 2-5…2-5). Start = begin with numbers 1 or 10/letters A or Z. NError = include 0 or number greater than 10. Linguistic = acronyms or words.

For the nonrandom generation tasks that included numbers and letters (nRNG, nRLG), a MANOVA did not show significant differences between the subgroups, Wilk's $\Lambda = .94$, $F(6, 242) = 1.33$, $p = .24$.Similarly, when the analysis considered the number of items that were produced as a function of randomness without consideration of errors (i.e., NDifference, LDifference), the MANOVA again showed no significant differences between groups, Wilk's $\Lambda = .97$, $F(6, 242) = 0.62$, $p = .71$.

Next, to assess the effects of the task manipulations across the nonrandom and random generation tasks MANOVAs for repeated measures were performed. This was completed because I assumed that performance was not independent across the measures. In these analyses, the control tasks (nRNG, nRLG), type of generation task (number versus letter), and the global inhibition tasks (RNG, RLG) constituted the within-subjects factors (number or letters, with or without EF component), whereas MD and non-MD groups were entered as between-subjects factors. The main effect for type of generation task was significant, Wilk's $\Lambda = .48$, $F(1, 122) = 131.39$, $p = <.0001$. As shown, the length of sequences for the nonrandom letter generation tasks (nRLG) were significantly less than on the nonrandom number generation tasks (nRNG). The main effect for inhibition tasks was also significant, Wilk's $\Lambda = .12$, $F(1, 122) = 1020.99$, $p = <.0001$. The length of sequences of the global random generation tasks (RNG, RLG) was significantly less than on the nonrandom generation tasks (nRNG, nRLG). The type of generation task by group interaction was not significant, Wilk's $\Lambda = .96$, $F(3, 122) = 1.61$, $p = .19$, nor was the inhibition task by group interaction, Wilk's $\Lambda = .99$, $F(3, 122) = .24$, $p = .87$.

A significant interaction emerged for the type of generation task by inhibition task interaction, Wilk's Λ = .37, $F(1, 122) = 205.43$, $p = <.0001$. The length of sequences on the random number generation tasks (RNG) was significantly less than on the random letter generation tasks (RLG). However, the type of generation task by inhibition task by Group interaction was not significant, Wilk's Λ = .97, $F(3, 122) = 1.44$, $p = .23$.

The results were followed by an examination of the children's item production as a function of random generation with correction for errors. For this global measure of randomness, only numbers or letters correctly produced in random order were counted (i.e., RNG, RLG). In this analysis, the inhibition tasks (RNG and RLG) constituted the within-subjects factor, whereas MD and nonMD groups were entered as between-subjects factors. In contrast to the above analyses, a MANOVA was significant for ability group, Wilk's Λ = .89, $F(6, 242) = 2.40$, $p = .03$. Furthermore, a follow-up with an ANOVA indicated that the group effect only occurred for the global inhibition measure related to random letter generation (RLG), $F(3, 125) = 4.26$, $p = .007$. A Tukey Test found significant differences ($p <.05$) between the control group and one MD subgroup (low calculation and low word problem solving).

In summary, as expected these results showed higher performance for nonrandom generation than random generation tasks and higher performance for nonrandom number generation than nonrandom letter generation. Next, when the inhibition component was included the results showed higher performance for random letter generation than random number generation tasks. However, these effects were not particularly robust across subgroups. The results did show, however, when errors related to randomness on letter generation tasks were taken into consideration children with MD who were low in both calculation and problem solving skills underperformed children without MD. These results support the second research hypothesis that children with MD vary significantly from children without MD on inhibition tasks based on a global measure of randomness.

In order to further refine my analyses, the groups were compared on the types of errors as a function of the individual randomness indices for the random number and letter generation tasks. The first analysis compared the four groups on all *number* error indices as the dependent measures (NDifference, NSeries1, NSeries2, NRepetition, NRedundancy, NRepeatPattern, NError, NStart). A comparison of group means using a MANOVA did not show significant differences between groups, Wilk's $\Lambda = .91$, $F(24, 334) = 0.47$, $p = .99$. No significant effects emerged for the individual number generation randomness indices.

The next analysis focused on errors isolated for the random *letter* generation task. The dependent measures were LDifference, LSeries1, LSeries2, LRepetition, LRedundancy, LRepeatPattern, Linguistic, and LStart. The MANOVA yielded a significant group effect, Wilk's $\Lambda = .73$, $F(24, 334) = 1.59$, $p = .04$. A follow-up with an ANOVA indicated that the group effect only occurred for the randomness index Letter Series 2 (LSeries2-a tendency to alphabetize in steps of 2), $F(3, 125) = 6.51$, $p = .0004$. A Tukey Test found significant differences (ps $<.05$) between the groups: Group 2 (average calculation-low word problem-low reading comprehension) < Group 3 (average calculation-average reading comprehension-low word problem); Group 2 < controls, and

Group 2 < Group 1 (low calculation-low word problems). No other significant effects emerged for the individual random letter generation randomness indices.

In summary, the results of the more refined analyses support the hypothesis that children with MD vary significantly from children without MD on inhibition tasks. However, only one specific randomness index for letter generation tasks was significantly related to math performance. This finding was isolated to children with low word problem solving combined with low reading comprehension skills.

Discussion

The results of the analyses lead to three main conclusions: 1) performance on global measures of inhibition are predictive of word problem skills as opposed to calculation skills; 2) children with more pervasive math difficulties (low calculation concurrent with low word problem skills) vary significantly from children without MD on global measures of inhibition; and 3) inhibition deficits of children with MD are not domain specific to numerical stimuli.

Inhibition as a Predictor of Math Achievement

Consistent with previous studies focusing on the relationship between math achievement and the EF component inhibition, evidence that performance on global measures of inhibition predicts math achievement was found (e.g., Bull & Scerif, 2001; Passolunghi & Siegel, 2004; Swanson & Beebe-Frankenberger, 2004; van der Sluis et al., 2004). However, this evidence was solely supportive of the ability for inhibition performance to predict the specific domain of word problem skills, and not predictive of calculation skills. This goes against results of previous research showing the relationship between the EF component of inhibition (attentive behavior) and calculation skills, but not problem solving skills (Fuchs et al., 2008; Furst & Hitch, 2000; Swanson, 2006). Nonetheless the present results are in line with other aspects of the literature, which proposed that different cognitive processes may support the acquisition of calculation versus word problem skills (e.g., Passolunghi & Pazzaglia, 2005; Passolunghi & Seigel, 2001). Specifically, it has been proposed that EF skills impact organization of math problems and ability to apply strategies for successful math problem solving (Mazzocco & Myers, 2003). As suggested by Censabella and Noel (2008), inhibition of irrelevant information may be less important when completing calculation problems whereas inhibition abilities contribute more to accuracy of solving word problems. Furthermore, word problem deficits are possibly associated with more pervasive cognitive impairments (Furst & Hitch, 2000; Fuchs et al., 2005, 2008).

The domain-specific inhibition deficit hypothesis proposed in the literature asserts that math disabilities are linked to fundamental deficits in the processing of numbers (Bull & Scerif, 2001; Passolunghi & Siegel, 2001; Willburger et al., 2008). Therefore, children with MD will exhibit inhibitory deficits uniquely when tasks consist of numerical stimuli. Presently, the performances on the RNG and RLG do not provide support for the domain- specific inhibition deficit. The present results differ in that the combined performances on random number and letter generation tasks (Factor 3 – RNG/RLG) predicted math achievement. Furthermore, a randomness index for letter generation, but not number generation, was significantly related to math performance. These results are in line with findings from other work in the field of inhibition-MD showing that inhibition deficits of children with MD are domain independent (D'Amico & Guarnera, 2005; Passolunghi & Siegal, 2004; Zhang & Wu, 2011). More accurately, this relationship appears to be associated with a general inhibitory deficit.

In summary, this research suggests that the relationship between the EF component inhibition and math achievement that has been supported in previous research may actually be more specific to the distinct mathematical domain of math word problem solving. Secondly, this relationship was not based on domain-specific or number only stimuli. In the present study performance on the combination of random number and letter inhibition measures was found to predict word problem solving as opposed to calculation skills.

Inhibition and Individual Differences in Math Skills

Multivariate analyses of variance were conducted to examine whether significant differences emerged among the subgroups on the non-random (control tasks) and inhibition measures. The total sample was divided into four subgroups as follows: children with low calculation-low word problem solving skills, children with average calculation-low word problem solving skills, and children with average calculation-low word problem solving-low reading comprehension skills, and children with average performance on all classification measures. Findings of the present study show that despite a rather small sample size the results are consistent with some aspects of the literature. In general it was expected that the degree of inhibition deficit would play a role in identifying individual differences in math achievement. This was found; however, it was specific to one inhibition measure and exclusively for the concurrent calculation-word problem MD group. Thus, the MANOVAs supported the general hypotheses that: 1) difficulties related to inhibition are significantly related to math performance, and 2) children with MD vary significantly from children without MD on inhibition tasks. The children with concurrent low calculation and low word problem skills showed greater inhibition deficits than the non-MD or control group when the inhibition measure consisted of random letter generation tasks.

In contrast to the domain-specific math word problems and inhibition relationship, the present findings also showed that children with concurrent math difficulties (low calculation combined with low word problem skills) vary significantly from children without MD on global measures of inhibition. Fuchs et al. (2008) pointed out that cognitive profiles associated with achievement in a single math domain may also be present with concurrent calculation and word problem deficits. Accordingly, concomitant difficulty with calculation and word problems may not be a distinct form of MD, but rather a comorbid relationship between the difficulties in both domains.

The present results did not support the domain-specific inhibition deficit hypothesis associated with number generation tasks. This may be, in part, related to the differences between random number generation and random letter generation. While both have been accepted as measures of inhibition, letter generation tasks are thought to put a greater cognitive demand on the ability to access long-term memory (Fisk & Sharp, 2004). Differences in performance between number versus letter generation tasks for the total sample was shown in the present study. Overall, the children's performance was significantly lower on the nonrandom letter generation (nRLG) versus nonrandom number generation (nRNG) tasks. Accordingly, the task of writing the alphabet quickly may have a greater demand for access to information stored in long term memory. In contrast, with the addition of the inhibition component the children's performance was significantly lower on the random number generation (RNG) versus the random letter generation (RLG) tasks. This pattern may reflect the difference in the quantity of possible response options for numbers (10) versus letters (26). It may require a higher level of inhibition to produce the numbers 1 to 10 out of order since there are a fewer number of response options.

Furthermore, when the analysis focused on types of errors for the random number and letter generation tasks the relationship was significant for the specific letter randomness index of LSeries2 (the tendency to alphabetize in ascending or descending series in steps of 2 or A-C). This relationship was specific to the MD group with average calculation and below average word problem, as well as below average reading comprehension skills. This is in line with the literature proposing that reading comprehension skills may distinguish math problem-solving from calculation skills (Fuchs, et al., 2008). Moreover, students with comorbid math and reading deficits may experience more pervasive difficulties with math problem solving (Hanich, Jordan, Kaplan, & Dick, 2001).

General Implications of Findings

Largely, the body of research supports the hypothesis that different types of math skills are more dependent on executive functioning processes than other academic skills (e.g., Bull & Scerif, 2001; Passolunghi & Siegel, 2004; van der Sluis et al., 2004).

Specifically, the literature has supported the relationship between inhibitory control and calculation skills, but not problem solving skills (Fuchs et al., 2008; Furst & Hitch, 2000; Swanson, 2006). In contrast, the results from the present study suggest a stronger relationship between inhibition and domain-specific, math word problem solving skills. This view of the EF-MD link is consistent with conclusions drawn by Censabella and Noel (2008) in that poor executive functioning has less impact on accurate calculation skills than accurate problem solving skills. That is, the additional demands required for successful math word problem solving, constructing a number sentence and deriving a calculation problem for producing a solution, draw more heavily on the EF component of inhibition. As the present work suggests, poor performance on measures of inhibition may be more indicative of a child being at-risk for development of word problem solving strategies. Thus, a model of mathematical competence that considers executive functioning skills-- specifically inhibitory control-- as a distinct characteristic of mathematical cognition may have greater potential for identifying students at risk for poor math word problem solving performance. In part, as emphasized by Fuchs et al. (2008), it may be warranted for specialists working in the school setting to consider calculation skills and word problem skills independently when evaluating students suspected of struggling with math deficits. Furthermore, as highlighted by Munro (2003), the fact that MD can arise either as a specific area of deficit or as part of a broader academic deficit causes the identification of MD to be much more complex. Subsequently, appropriate identification of MD and intervention strategies for MD is even more crucial.

The results of the present study are relevant to both researcher and educational practitioners. Researchers focused on the areas of executive functioning and math achievement may find this examination useful in guiding future studies in this area. Aspects of future research need to consider characteristics of EF tasks, as well as specific math domains. Additionally educational practitioners may benefit from the findings ascertained from this study of math skills and inhibition abilities. School psychologists should note the utility of different types of inhibition measures as potentially useful tools for the assessment and identification of math disabilities. In addition, teachers developing and implementing math intervention may profit from a greater understanding of the influences of executive functioning on math achievement.

General Limitations of Study

The results of the present study provide further support for a relationship between inhibition and mathematics. Nevertheless, some limitations of this study need to be pointed out. First of all, a larger sample size would have increased statistical power, as well as providing the potential for using more restrictive criteria to define MD. The use of more restrictive criteria to define MD is in line with the view that EF deficits may identify children with more pervasive MD, as well as the ability to focus on concurrent subtypes of MD (Mazzocco & Myers, 2003). In addition, the age range was limited thus the results cannot readily be generalized to all school age children. Missing from the present study, is the inclusion of multiple age groups, either by means of a longitudinal or cross-sectional design. The literature supports a continuation of EF development from early childhood into adolescents (Brocki & Bohlin, 2004; Huizinga et al., 2006).

Furthermore, because in contrast to acquisition of basic reading skills, math concepts are cumulative beyond the primary grades and math difficulties may manifest during different stages of a child's schooling (Geary, 1993; Mazzocco & Myers, 2003). Thus, capturing measures of the EF-MD relationship at one point may not be indicative of a prolonged or ongoing link. Additionally, the present study did not consider the influence of the extraneous factors on development of mathematic skills, such as motivational, educational, and social aspects (Bull et al., 1999). Previous research has shown that experiences outside of school may have a relationship with the development of mathematical problem solving (Fuchs et al., 2008).

Next the present study examined the relationship between the type of inhibition errors and accuracy scores on separate measures of both calculation and word problems. However, the math measures did not allow for analysis of different types of math errors, enabling only general conclusions. It has been proposed that greater insight into the MD relationship to inhibition deficits may be gained from analyzing the type of MD errors or types of strategies used to complete math problems (Van der Ven et al., 2012). For math achievement several cognitive processes that fall under the umbrella of executive functioning are thought to be specifically related to successful problem solving. The ability to be flexible when choosing problem solving strategies, specifically inhibition of dominant yet false answers or immature strategies, may contribute to accurate problem solving. An important factor may be the distinction between students who use poor strategies, versus students who use mature strategies but make simple errors (Van der Ven et al., 2012). Additionally, as noted previously problem solving strategies may vary throughout the different stages of a child's schooling (Geary, 1993), thus a child may use poor strategies at one point followed by making simple errors at a later stage.

As for the inhibition measures, the present study included the use of control tasks along with random generation tasks in the research design to address the impurity problem inherent in the measurement of executive functions. A preferred random generation task design consists of a non-random (numbers/letters in order) trial as the control task, followed by the random (numbers/letters out of order) trial (e.g., van der Sluis et. al, 2004; Zhang & Wu, 2011). The present results showed that with the addition of the inhibition component the children's performance across the total sample was significantly lower on the generation tasks, specifically the random number generation tasks. Nevertheless, the present study only used one type of inhibition measure, the number-letter generation tasks. As emphasized in the literature, each executive task also measures other non-executive skills based on the fact that EFs regulate various cognitive functions (Van der Ven et al., 2012). While the utility of random generation tasks as a measure of inhibition has been agreed upon amongst researchers (Baddeley et al., 1998; Jahanshahi et al., 2006; Miyake et al., 2000; Peters et al., 2007; Towse & Neil, 1998), the use of multiple inhibition measures would have increased the potential for addressing the impurity problem (Van der Ven et al., 2012).

More specifically, and of additional concern, the administration of the number letter generation tasks within the present study only provided for students to write numbers and letters as quickly as possible within a 30-second period (first "in order" followed by "out of order"). On the contrary, previous research employing the use of number generation tasks provided for participants to give 100 responses which generated a larger data set for error analysis (Fisk & Sharp, 2004; Zhang & Wu, 2011). Moreover, the use of available computer software for scoring and error analysis may afford a greater degree of accuracy in the results. In sum, the brief number and letter generation protocols obtained from the present study may not have produced an adequate data set for an overall measure of inhibition, and even less probable for an analysis of specific types of inhibition randomness indices.

Future Directions

Having mentioned the limitations of the present study, it is within reason to conclude that this work has the potential to make some contribution to the current body of literature focusing on the inhibition-MD relationship. Moreover, it also highlights a number of directions for future study. Theoretically, this body of work, particularly the review of literature calls into question the multicomponent model of executive functioning. Given the inconsistencies in the literature, continued investigation is warranted to support the proposal that the executive functioning consists of unitary and diverse components, with a goal to further delineate the characteristics of these components across the developmental span. That is, are shifting, updating, and inhibition factors distinguishable from each other? Thus, informing whether or not the design of studies in the area of EF-MD relationship should consider the measurement of these EF components separately. If so, how do the characteristics of these EF components change across the developmental span in relation to the sequence of math curriculum? Furthermore, the results from this study emphasize the need for potential next steps.

Primarily, this body of work points out the need for studies in the field of mathematics to consider calculation and word problem solving as distinct math domains. Thus, employing the use of specific versus broad mathematic measures for classification of MD is essential. One more direction involves continued examination of the domain-specific inhibition deficit hypothesis which asserts that math disabilities are associated with fundamental deficits in the processing of numbers. Initial steps have been made to broaden the study of the inhibition deficit-MD relationship to include older children and additional math concepts such as algebra (Khng & Lee, 2009; Lee, Ng, E.L., & Ng, 2009). In addition, literature in the area of math disabilities has acknowledged the utility of different MD definitions and MD subtypes, including the differentiation of cognitive processes underlying calculation skills as being distinct from those of word problem solving skills, which is a promising direction for the study of this complex area of academic achievement (Mazzoco & Myers, 2003). Continued integration of the neuropsychological field with the field of educational psychology has the potential for increased understanding of the underlying cognitive processes that support the development of math skills and subsequent directions for the study of instructional strategies for students at risk for math disabilities.

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Appendix A

Administration Instructions for Inhibition Measures

1. Fold paper in half, along the dotted lines, with the "Letter Generation Task" side up.
2. Say the following directions to the student:

"Go to side A1 (the Letter Generation Task). When I say 'go' I want you to write all the letters of the alphabet, in order, like a, b, c, d, as fast as you can. You will need to stop writing when I say 'stop'." [*Tell older students that if they get to Z before hearing "stop", they should write the alphabet again*.] "**Do this as quickly as you can. Ok? Ready…GO!"** (Time student for 30 seconds.)

3. Flip the paper over to reveal the "Random Letter Generation" side.
4. Say the following directions to the student:

"Go to side A2 (the Random Letter Generation Task). Now I need you to do something a little different. When I say 'Go' I want you to write the letters of the alphabet NOT in order, like Z, R, T, A. Do not write the letters in order, like last time. Instead, pick ANY letters from the alphabet you want. [*For older or verbally sophisticated young students add***—Also, do not write any real words, like your name, and try not to use the same letters more than once. Just pick random letters from the alphabet. If you use all of them up, you can start again.]** Remind students to "**Write the alphabet on one line and then go to the next line." Do this until I say 'Stop'. Ready …Go!"** (Time students for 30 seconds).

5. *If a student needs a prompt to remind them not to write letters in order, tell them*, "**Remember, we want you to write the letters out of order.**"

6. For the number part of the test, fold the paper over to the "Number Generation Task" side and place before student.
7. Say the following directions to the student:

"Go to side B1 (the Number Generation Task). When I say 'Go' I want you to write the numbers 1 through 10 over and over, like 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 1, 2, 3…etc. as fast as you can. But you can't use zero as a number, only 1 through 10. You will need to stop writing when I say 'Stop'. Do this as quickly as you can. Ok? Ready….Go!" (Time student for 30 seconds).

8. Flip paper over to "Random Number Generation" side. Say the following:

" Go to side B2 (the Random Number Generation task). Now I want you to write numbers between 1 and 10 but this time out of order, like 1, 5, 2, 8 over and over. Don't forget to randomly use all the numbers between 1 and 10. If you use all of the

numbers up, you can start again. Do this until I say 'Stop'. Ready…Go! (Time student for 30 seconds). If a student asks, the **number zero** is **not** to be used—just numbers 1-10.

Appendix B

Number Generation Randomness Indices

Numbers in sequential order (nRNG) Raw score = 30

1-2-3-4-5-6-7-8-9-10-1-2-3-4-5-6-7-8-9-10-1-2-3-4-5-6-7-8-9-10-1-2-3-4-5-6-7-8-9-10

Numbers out of order Raw score = 16

10-8-7-6-5-9-1-4-10-8-3-10-6-5-9-1-9

Number Difference (NDifference)

Difference measured the number of digits in the nRNG task minus the number of digits in the out of order task without consideration of randomness errors, for example NDifference = 30-16 = 14. This reflects the reduction in the quantity of numbers when the inhibition component is added.

Random Number Generation (RNG)

Random number generation represents a global measure of randomness in that only numbers written in random order were counted, for example (10-8-7-6-5-**9-1-4**-10-8-**3-10**-6-5-**9-1-6**); RNG = 8.

Number Repetition (NRepetition)

Repetition measured the number of identical pairs or tendency to produce repeated digits, for example (4-4) = 1 (10-8-7-6-5-9-4-4-10-8-3-10-6-5-9-1-9); NRepetition = 1.

Number Redundancy (NRedundancy)

Redundancy measured the tendency to repeat the same digit within a series of 10 item (10-8-7-6-5-9-3**-10**-8**-4-10**-6-**4-9**-1-**9);** NRedundancy = 3.

Number Series1 (NSeries1)

When calculating the series scores the length of the series was squared to give higher weights to longer runs or counting sequences. Number Series 1 (NSeries1) measured the number of consecutive digrams or tendency to count in ascending or descending series in steps of 1, for example (5-6) = 1^2 or 1 and (8-7-6-5) = 3^2 or 9 (10-**8-7-6-5**-9-1-4-10-8-3-10-**5-6**-3-1-9); ascending series = 1; descending series = 9; NSeries1 = 10.

Number Series2 (NSeries2)

Number Series 2 (NSeries2) measured the tendency to count in ascending or descending series in steps of 2, for example (8-10) = 1 and (10-8-6) = 2^2 or 4 (**8-10**-7-2-5-9-1-4-**10-8-6**-10-6-5-9-1-9); ascending series = 1; descending Series = 4; NSeries2 = 5.

Number Repeat Patterns (NRepeatPattern)

Number repeat patterns measured the tendency to produce digram repetitions, for example, (10-8….10-8) = 1 (**10-8**-7-**6-5-**1-**5-9-**3-**10-8**-4**-**10-**6-5-**8-**5-9**); NRepeatPattern = 3.

Number Error (NError)

Number error measured the inclusion of any numbers other than 1 to 10.

Number Start (NStart)

Number start measured the tendency to start RNG sequences with the numbers 1 or 10 (**10-**8-7-6-5-9-1-0-10-8-0-10-6-5-9-1-9); NStart = 1.

Appendix C

Letter Generation Randomness Indices

Letters in alphabetical order (nRLG) Raw score = 35

A-B-C-D-E-F-G-H-I-J-K-L-M-N-O-PQ-R-R-S-T-U-V-W-X-Y-Z-A-B-C-D-E-F-G-H-I

Letters out of order Raw score = 17

D-X-Y-V-Z-Q-C-B-L-M-N-O-T-Q-T-S-E

Letter Difference (LDifference)

Letter difference measured the number of letters in the nRLG task minus the number of letters in the out of order task without consideration of randomness errors, for example LDifference = 35-17 = 18. This reflects the reduction in number of letters when the inhibition component is added.

Random Letter Generation (RLG)

Random letter generation represents a global measure of randomness in that only letters written in random order were counted, for example (**D**-X-Y-**V-Z-Q**-C-B-L-M-N-O-**T-Q**-T-S-**E**); RLG = 7.

Letter Repetition (LRepetition)

Repetition measured the number of identical pairs or tendency to produce repeated letters, for example (M-M) = 1 (D-X-Y-V-Z-Q-C-B-**M-M**-N-O-T-Q-T-S-E); LRepetition = 1.

Letter Redundancy (LRedundancy)

Redundancy measured the tendency to repeat the same letter within a sequence of 10 items (D-X-Y-V-Z-Q-C-B-L-M-N-O-**T**-Q-**T**-S-E); LRedundancy = 1.

Letter Series1 (LSeries1)

When calculating the series scores the length of the series was squared to give higher weights to longer runs or alphabet sequences. Letter Series 1 (LSeries1) measured the number of consecutive digrams or tendency to alphabetize in ascending or descending series in steps of 1, for example (C-D) = 1^2 or 1 and (L-M-N-O) = 3^2 or 9 (D-**X-Y**-V-Z-Q-**C-B-L-M-N-O**-T-Q-**T-S**-E); ascending series = 1; descending series = 9; LSeries1 = 10.

Letter Series2 (LSeries2)

Letter Series 2 (LSeries2) measured the tendency to alphabetize in ascending or descending series in steps of 2, for example (A-C) = 1 or (P-N-L) = 2^2 = 4; ascending series = 1; descending series = 4; LSeries2 = 5.

Letter Repeat Patterns (LRepeatPattern)

Letter repeat patterns measured the tendency to produce digram repetitions, for example (A-E….A-E) = 1 (D-X-Y-V-**Z-Q**-C-B-L-M-N-O-**Z-Q**-T-S-E); LRepeatPattern = 1.

Letter Start (LStart)

Letter Start measured the tendency to start RLG with the letters A or Z (A-X-Y-V-Z-Q-C-B-L-M-N-O-T-Q-T-S-E); LStart = 1.

Linguistic Patterns (Linguistic)

Linguistic patterns measured the tendency to produce letter stereotypical schemas such as acronyms or words, for example (N-B-C) = 1 or (T-O-P) = 1 (D-X-Y-V-Z-Q-**C-A-T**-M-N-O-T-Q-T-S-E); Linguistic = 1.